BUKTI KORESPONDENSI
ARTIKEL JURNAL INTERNASIONAL BEREPUTASI

Judul Artikel : Using Arduino and Online Block-Structured Programing Language for Physics Practical Work

Jurnal : **Physics Education Vol 56 No 5 (2021) 055028**

Penulis : Elisabeth Pratidhina, Dadan Rosana, Heru Kuswanto, Wipsar Sunu Brams Dwandaru

No	Perihal	Tanggal
1.	Bukti submit artikel dan artikel yang disubmit	5 Maret 2021
2.	Bukti hasil review (revision)	8 April 2021
3.	Bukti submit revisi	21 April 2021
4.	Bukti hasil review kedua	6 Mei 2021
5.	Bukti submit revisi kedua	12 Mei 2021
6.	Bukti review ketiga (provisionally accepted)	21 Mei 2021
7.	Bukti artikel accepted	8 Juli 2021
8.	Bukti submit proof correction	14 Juli 2021
9.	Bukti konfirmasi final check	21 Juli 2021
10.	Bukti published online	28 Juli 2021

1.	**Bukti submit artikel dan artikel yang disubmit**	**5 Maret 2021**

Gmail

Elisabeth Founda <elisa.founda@gmail.com>

Your submission to Phys. Educ.: PED-102718

1 message

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Dear Miss Pratidhina,

Re: "Using Arduino and Online Block-Structured Programing Language for Physics Practical Work" by Pratidhina, Elisabeth; Rosana, Dadan; Kuswanto, Heru
Article reference: PED-102718

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Letter reference: SAu05

Using Arduino and Online Block-Structured Programing Language for Physics Practical Work

Elisabeth Pratidhina[a,b], Dadan Rosana[a], Heru Kuswanto[a], Wipsar Sunu Brams Dwandaru[a]

[a] Universitas Negeri Yogyakarta, Jl. Colombo No. 1, Karang Malang, Caturtunggal, Depok, Sleman, Daerah Istimewa Yogykarta 55281.

[b] Department of Physics Education, Widya Mandala Catholic University Surabaya, Jl. Kalijudan 37 Surabaya 60114

Abstract

Distance learning in physics is still facing challenges, mainly due to the difficult access to a laboratory for practical work. Practical work is an essential part of the physics classroom because it allows students to interact with authentic physics phenomena and develop their scientific abilities. In this paper, we propose alternative experiments that can be carried out at home with affordable apparatus. We explain the use of Arduino UNO board and block-structured programming environment to design physics experiments about investigating light-emitting diode (LED) and capacitor characteristics. Block-structured programming in the common-coding builder is used because it has extension features such as plotting data in a graph directly and programming the Arduino board. Moreover, a user with no prior knowledge of programming can use it easily.

Keywords: Arduino, physics, practical work, block-structured programming, distance learning

1. Introduction

In the past, the distance learning mode's main obstacle was the lack of interaction among students and teachers. The advanced communication technology that we have nowadays has a significant impact on the distance learning process. The interaction among students and teachers during distance learning has been tremendously enhanced by various communication platform and learning management system. However, teaching physics in distance learning mode is still challenging.

Practical work plays an essential role in physics education to develop students' scientific ability, understand the process of scientific investigation, and connect the real physical world with theory [1–3]. The challenge for physics education in distance learning mode is bringing students to experience laboratory work effectively and safely. There are some alternatives for this challenge, including using computer simulations and portable experiment kits [4,5]. Computer simulation may engage students in scientific processes such as manipulating variables, observing phenomena, and analyzing the relationship among variables. However, it cannot bring authentic laboratory experience. Students can physically work on objects, practice using instruments safely, be aware of real measurement uncertainty, observe the real phenomena, and create conceptual models of the physical world.

Students may perform laboratory work at home by using an experiment kit. There are various experiment kits in the market, but they are mostly pricy and only can be used for specific experiment topics. However, the recent development of low-cost microcontrollers and sensors offers feasibility in bringing affordable physics experiment tools for distance learning [6].

Arduino is a low-cost microcontroller that has been widely used for physics education [7–10]. It can be connected with various sensors to measure a lot of physical quantity [8,11,12]. Usually, Arduino programing use C or C++ programming language. However, it might be difficult for a teacher to implement the programing language in the physics classroom because students may not have prior knowledge about computer programming[13]. Fortunately, a user-friendly programming environment, called block-structured programming language, can be used to program Arduino. In a block-structured programming language, the developer only needs to drag and drop the blocks to construct a program, and they do not have to memorize the syntax to write the code.

This paper shows the use of Arduino and block-structured programming language provided in common-coding builder[14] for a didactic physics experiment about investigating capacitor and LED characteristics. Common-coding builder is based on Scratch, a widely-used block-structured programming language in STEM education[15]. However, the common-coding builder offers extension features such as chart, google sheet, and Arduino programming. Those features are useful for setting up physics experiments with Arduino, getting and analyzing the data.

2. Investigating The Characteristic of LED

2.1 Hardware Set-Up

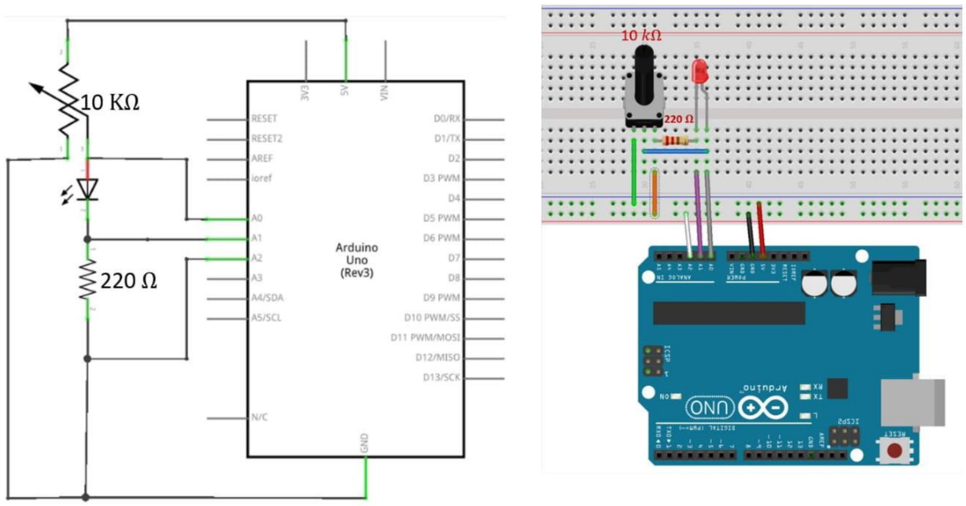

Figure 1. The circuit used in the experiment to investigate the characteristic of LED

In this experiment, the apparatus consists of an Arduino UNO board, a USB serial cable, LEDs, a 220 Ω resistor, a $10k\Omega$ potentiometer, a breadboard, a computer with Windows operating system, and internet connection. The circuit diagram to investigate the characteristic of LED is shown in Figure 1a. In this set-up, Arduino UNO is used as a voltage source, a current, and a voltage sensor. A potentiometer is used as a voltage divider. By adjusting the potentiometer, we can change the voltage across LED, and then measure the current.

2.2 Programing

To program Arduino UNO for a voltage source, a current, and a voltage sensor, we have to program it through the common-codding builder. Common-coding builder can be accessed online using a browser in https://common-coding.com/. The initial layout is presented in Figure 2. To allow Arduino programming, we need to choose Arduino Windows extension (see Figure 3); after that, download and run firmware to connect the Arduino Uno hardware to the software. The code to program Arduino UNO in investigating the characteristic of LED is shown in Figure 4. In this set-up, voltage and current are measured from the value recorded by the analog pin of Arduino UNO.

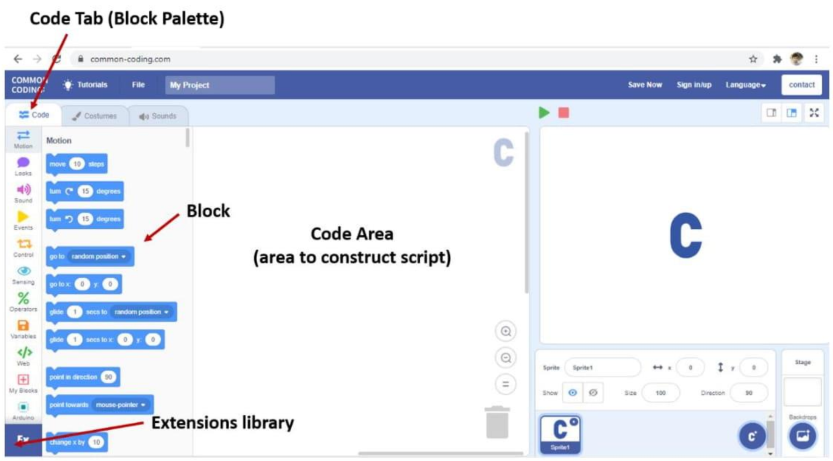

Figure 2. The layout of common-coding builder

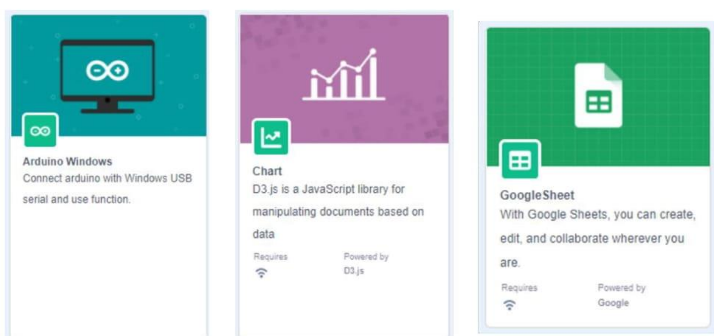

Figure 3. Some extensions library in common-coding builder, i.e. Arduino Windows, Chart, and Google Sheet

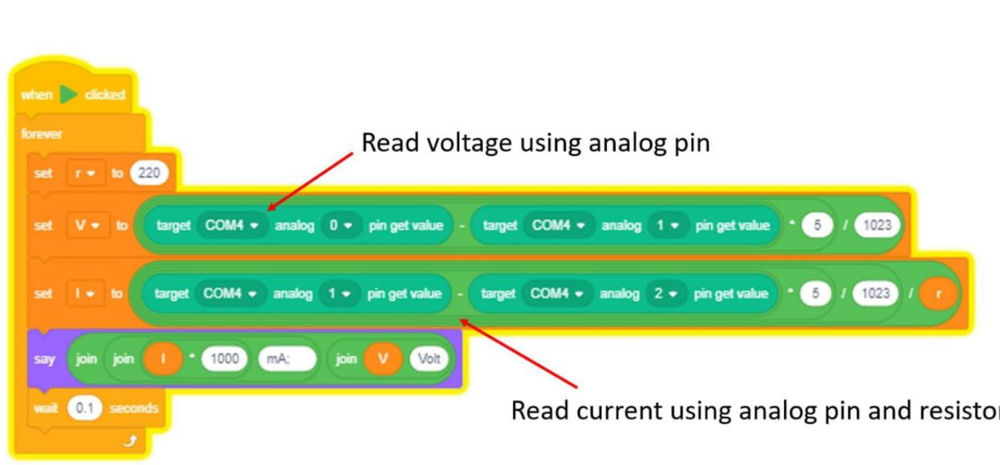

Figure 4. The code for investigating LED characteristic using the common-coding builder environment

2.3 Discussion

Typically, LED consists of semiconductors materials which has an energy bandgap. Enough applied voltage can cause electrons to jump from one material to another. The electron transition from the conduction to the valence band causes light-emitting. The voltage at which the first transition occurs is called threshold voltage. The first transition can be observed from the first light emitted or the first current measured in the circuit. The energy band gap of each LED can then be calculated with the equation (1). Each type of LED is fabricated from various semiconductor materials; thus, they have various energy bandgap. Different semiconductor materials will produce multiple colors.

$$E_{gap} = e\, V_{threshold}. \qquad (1)$$

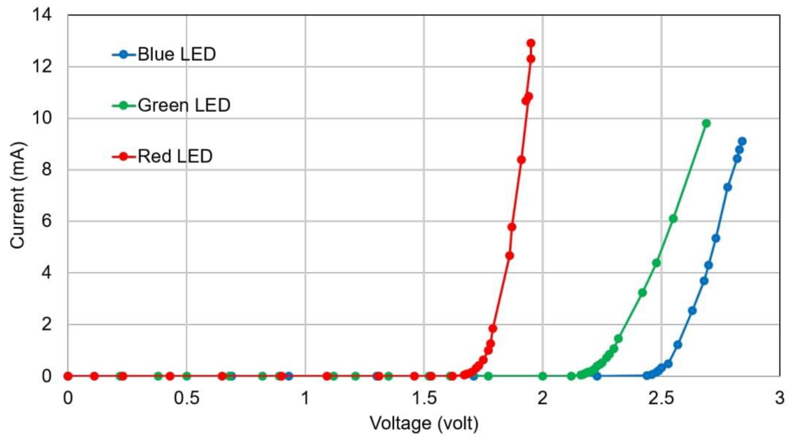

Figure 5. Voltage-current relationship in red, green, and blue LED at room temperature

In this experiment, we investigate the voltage-current relationship in red, green, and blue LEDs. As shown in Figure 5, for low applied voltage, current cannot flow through the LED. After the applied voltage is surpassing a specific threshold voltage, the current starts to flow. Table 1 presents the measured threshold voltage. Current in red LED starts to flow when the applied voltage is around 1.67 V. For green LED, the applied voltage should be higher than 2.16 V to allow current flow. Meanwhile, the blue LED requires the highest applied voltage, i.e., 2.46 V, to allow current flow.

The experiment may help students to understand how circuit with LED works. It also can introduce the quantum properties of solids to students. Furthermore, this experiment can be extended with more colors of LED for determining the Planck constant value[16].

Table 1. The energy band gap of various color LED

LED	$\boldsymbol{V_{threshold}}$ (eV)	$\boldsymbol{E_{gap}}$ (eV)
Red	1.67	1.67
Green	2.16	2.16
Blue	2..46	2..46

3. Investigating Capacitor

3.1 Hardware set-up

The purpose of the 'investigating capacitor' experiment is to plot the capacitor voltage as a function of time during the charging and discharging process. The equipment consists of an Arduino Uno board, a USB-serial cable, a capacitor, a voltage sensor, a resistor, a breadboard, jumper wires, a computer with Windows operating system, and an internet connection. The equipment set-up is presented in Figure 6. In this set-up, a digital pin of Arduino Uno is used as a voltage output because it can be easily switched ON for charging the capacitor and switched OFF for discharging the capacitor.

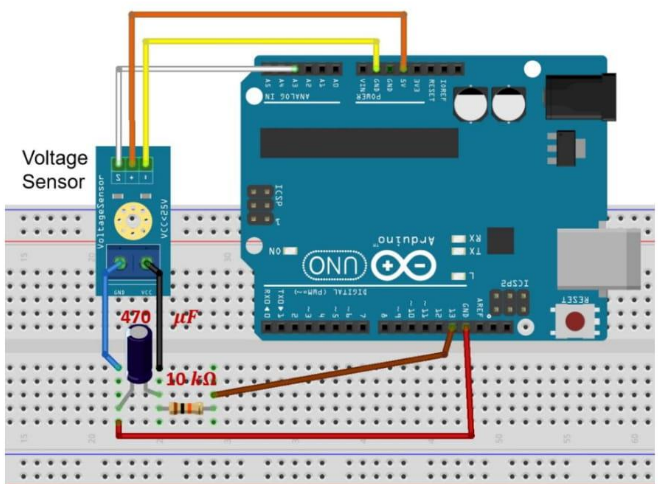

Figure 6. 'Investigating Capacitor' Experiment Set-up

3.2 Programing

The code used for charging and discharging capacitor is presented in Figure 7 and 8, respectively. During the charging process, the digital pin output is set as 1 (HIGH) for supplying voltage. Meanwhile, when discharging cycle, the digital pin output is set as 0 (LOW) to cut the voltage supply.

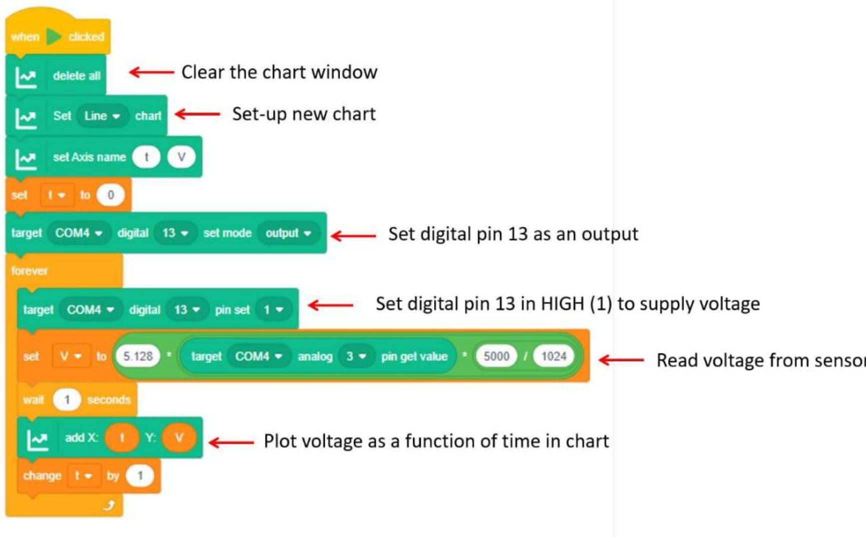

Figure 7. Code for investigating time-varying capacitor voltage during charging process

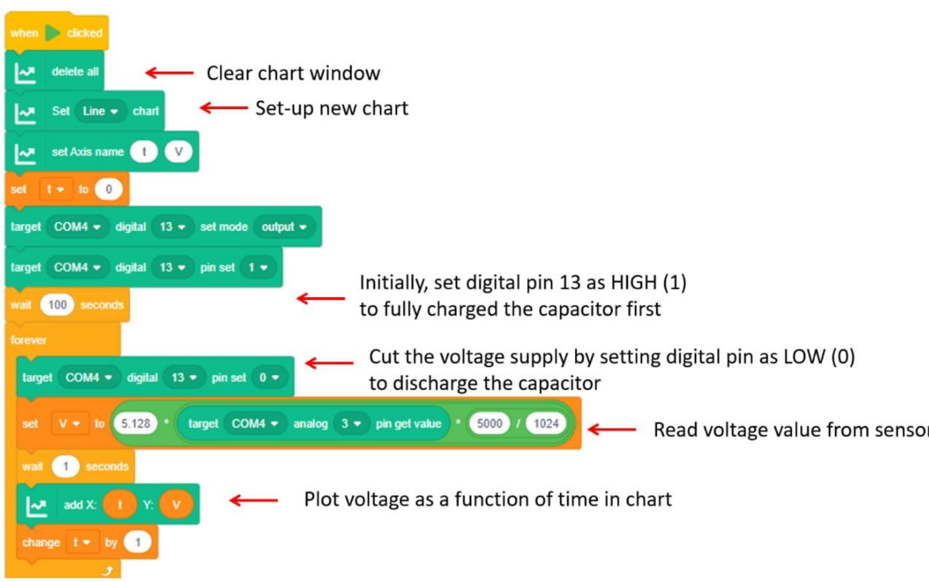

Figure 8. Code for investigating time-varying capacitor voltage during discharging process

3.3 Discussions

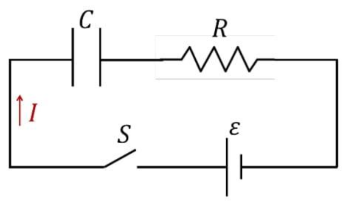

Figure 9. Basic circuit for 'investigating capacitor' experiment

The basic diagrammatic circuit for the charging capacitor can be seen in Figure 9. When a voltage source is connected to the capacitor and the resistor, analysis with Kirchhoff rule will give:

$$\varepsilon - \frac{q}{C} - IR = 0 \qquad (2)$$

Where ε is the voltage source, IR is the voltage across the resistor, and $\frac{q}{C}$ is the voltage across the capacitor. By substitute $I = \frac{dq}{dt}$ and dividing all terms by R, Eq. 1 can be written as:

$$\frac{\varepsilon}{R} - \frac{q}{RC} - \frac{dq}{dt} = 0$$

$$\frac{dq}{dt} = -\frac{q - C\varepsilon}{RC} \qquad (3)$$

By solving Eq. 3 and using an assumption that the capacitor is initially discharged, we can yield charge in the capacitor as a function of time, i.e.:

$$q(t) = C\varepsilon\left(1 - e^{-\frac{t}{RC}}\right) \qquad (4)$$

Since $V = q/C$, the voltage across the capacitor, $V_c(t)$ can be expressed as:

$$V_c(t) = \varepsilon\left(1 - e^{-\frac{t}{RC}}\right) \qquad (5)$$

When the voltage source is disconnected, the capacitor will discharge. Analysis with Kirchhoff rule will give:

$$-\frac{q}{C} - IR = 0 \qquad (6)$$

We can model the voltage across the capacitor during the discharge process within the same procedure as the analysis for capacitor charging. The voltage across capacitor during the discharging process can be modeled in Eq. 7.

$$V_c(t) = \varepsilon \exp\left(-\frac{t}{RC}\right) \qquad (7)$$

With the Arduino and common-coding builder software, voltage across the capacitor during the charge and discharge process has been measured real-time and directly plotted in graphs,

such as depicted in figures 10 and 11. Figure 10 shows the voltage as a function of time during the charging process. Initially, the capacitor voltage increases fast; then, the increment becomes slower until it reaches a steady maximum voltage. This result is in agreement with the theory presented in Eq. 5. Figure 11 shows the voltage-time graph when the capacitor is discharged. As predicted theoretically in Eq. 7, the experiment showed that the capacitor voltage decreases exponentially during the discharging process.

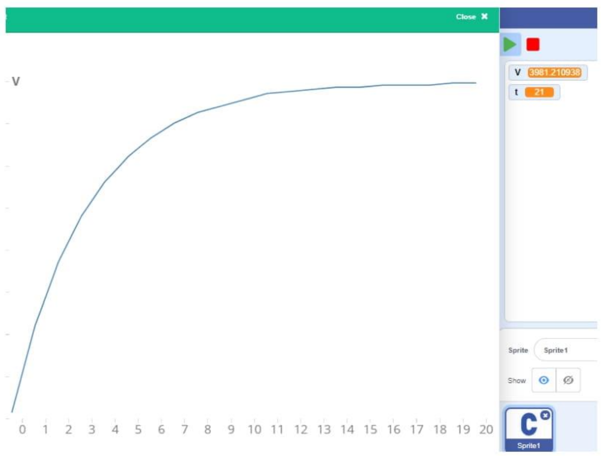

Figure 10. The time-varying voltage across capacitor during charging process presented in chart window available in common-coding builder. Voltage and time are in volt and second, respectively.

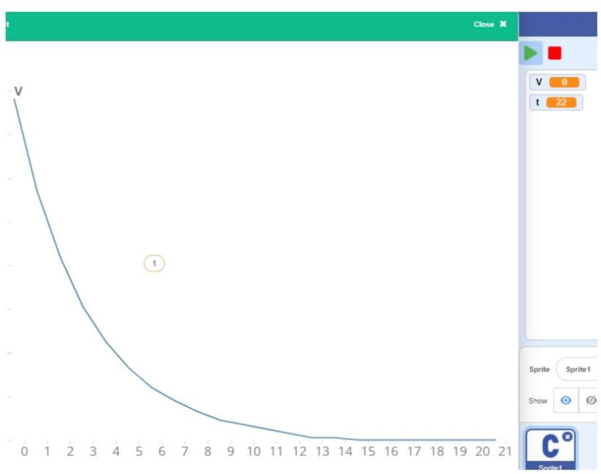

Figure 11. The time-varying voltage across capacitor during discharging process presented in chart window available in common-coding builder. Voltage and time are in volt and second, respectively.

Data visualization in the common-coding builder helps students understand physical phenomena with graph representation and connect experimental results with theoretical models. Moreover, with minimal knowledge of computer programming, students can do the activities at home.

4. Conclusion

Arduino and block-structured language programing, like common-coding builders, can be used to design various experiments to support physics learning. The apparatus is affordable, and the programming can be done easily by students who do not have prior knowledge of coding a program. Teachers can design experiments with various topics and assign students to try them at home. Since access to a laboratory is difficult for physics distance learning, this experiment can become an alternative to training students' practical skills, science process skills, and computational thinking skills. During a difficult time, such as the COVID-19 pandemic, it may be useful to support high school students or early year college students exploring physics from home.

5. Acknowledgments

The authors would like to thank Ministry of Research and Technology and Ministry of Education and Culture of Republic of Indonesia

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2. Bukti hasil review (revision) 8 April 2021

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Our initial decision on your article: PED-102718

1 message

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Dear Miss Pratidhina,

Re: "Using Arduino and Online Block-Structured Programing Language for Physics Practical Work"
Article reference: PED-102718

We have now received the referee report(s) on your Paper, which is being considered by Physics Education.

The referee(s) have recommended that you make some amendments to your article. The referee report(s) can be found below and/or attached to this message. You can also access the reports at your Author Centre, at https://mc04.manuscriptcentral.com/ped-iop

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Yours sincerely

Jessica Thorn

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REFEREE REPORT(S):
Referee: 1

COMMENTS TO THE AUTHOR(S)
Thank you for your article, which was most interesting.
In section 3.1 you use a voltmeter sensor, but do not explain why. The arduino has a perfectly good AD converter and unless the voltage exceeds 5V there is no reason to use the external board. If there is a reason, an explanation would be useful.
There is code to allow macOS to connect to the Arduino, but didn't test this.
My main concern is that having spent several hours on trying to get this to work, I was unable to obtain any readings. As a very experienced programmer of Arduino boards, I found setting up the usb link not very straight forward, having to run a script outside of the browser and then having to restart the browser (chrome) before it found the port.
Using the block programming is not that straightforward and I would suspect needs some prompting or prior teaching. Having used scratch, I still found the order in which to build the commands not as straight forward as indicated and it took well over an hour to copy your first script (in which time I could have coded it in C+ many times over), so would not assume that a beginner would be able to replicate your achievements without help.
I wrote a much simpler code in the block coding to read the analogue port A0 and display the output. This also did not work on either a Uno, Nano or Mega...all 3 failed to read the values. I don’t know if this was my port not communicating with the arduino, however writing a few lines of code in the IDE using exactly the same as fig 1 gave me the values immediately.
This is not to say that there is anything wrong with the paper, just if a very experienced programmer and user (>40 years) cannot obtain an output using the block programming language, then a learner who is doing this at home may struggle. The other issue is that as far as I can see, this needs an internet connection to be connected and so will not work in areas with poor connection, the IDE does not.

Letter reference: DSMo01

3. Bukti submit revisi 21 April 2021

Reply to the Reviewer's comments

Manuscript ID: PED-102718
Title: " Using Arduino and Online Block-Structured Programing Language for Physics Practical Work "

We appreciate valuable comments from the Editor and the Reviewers of Physics Education. As suggested by the Reviewers, we have strengthened our manuscript by revising the manuscript and added Supporting Information. We have carefully considered the Reviewer's comments and made appropriate changes as described below.

Response to the report of Reviewer 1

Comment 1) *In section 3.1 you use a voltmeter sensor, but do not explain why. The arduino has a perfectly good AD converter and unless the voltage exceeds 5V there is no reason to use the external board. If there is a reason, an explanation would be useful.*

Author reply) In the second experiment (Investigating Capacitor), there is no issue if we use Arduino to read the voltage since the measured voltage is less than 5V. We want to show readers another option to measure voltage by using a voltage sensor module. In the first experiment (Investigating The Characteristic of LED), we have shown how to use Arduino to measure the voltage. Using a voltage sensor module also allows the measurement of a broader range of voltage. To give a clearer explanation, we added sentences such as

" The voltage sensor is not compulsory; we can use an Arduino board to read the voltage as long as the measured voltage is less than 5V (See Supporting Information)."

Moreover, we provide Supporting Information to show the alternative of experimental set-up without voltage sensor module.

Comment 2) *There is code to allow macOS to connect to the Arduino, but didn't test this.*

Author reply) We were aware that it is our work limitation. We are unable to test it in MacOS because we do not have a MacOS device. Fortunately, all of my students use Windows OS devices. To address this limitation in our manuscript, we add sentences such as

"As a disclaimer, we test the common-coding builder in the Windows OS environment only due to the limitation of devices. However, the common-coding builder also provides features for Mac OS."

Comment 3) *My main concern is that having spent several hours on trying to get this to work, I was unable to obtain any readings. As a very experienced programmer of Arduino boards, I found setting up the usb link not very straight forward, having to run a script outside of the browser and then having to restart the browser (chrome) before it found the port. Using the block programming is not that straightforward and I would suspect needs some prompting or prior teaching. Having used scratch, I still found the order in which to build the commands not as straight forward as indicated and it took well over an hour to copy your first script (in which time I could have coded it in C+ many times over), so would not assume that a beginner would be able to replicate your achievements without help. I wrote a much simpler code in the block coding to read the analogue port A0 and display the output. This also did not work on either a Uno, Nano or Mega...all 3 failed to read the values. I don't know if this was my port not communicating with the arduino, however writing a few lines of code in the IDE using exactly the same as fig 1 gave me the values immediately. This is not to say that there is anything wrong with the paper, just if a very experienced programmer and user (>40 years) cannot obtain an output using the block programming language, then a learner who is doing this at home may struggle. The other issue is that as far as I can see, this needs an internet connection to be connected and so will not work in areas with poor connection, the IDE does not.*

Author reply) To connect common-coding builder to Arduino board, we have to pre-install some applications, such as Java and a firmware application, ccb_connect.exe. We create Supporting Information to explain detailed procedures to use common-coding builder; a video tutorial also accompanies it. We agree that to implement the activity in an online class, teachers have to give introductory tutorials about the technical procedure to use the common-codding builder. We also realize that students need a good internet connection in the implementation because this program works online. Beyond the existing weaknesses, this program has some advantages, such as allowing students to gain a foundation in computational thinking through visuals instead of coding based on text, like in IDE. Moreover, it also embeds a graph visualization feature that is very useful to represent a physics phenomenon.

To address the issues, in the manuscript, we added some sentences such as:

"The firmware application, ccb_connect.exe, is running in a Java environment. The complete procedure to allow connection between Arduino UNO and the common-coding builder for the first time is explained in the Supporting Information."

"Although common-coding builder has advantages such as introducing a foundation of computational thinking to students with minimal knowledge of programming, it has several limitations. First, to connect the common-coding builder to Arduino UNO, we need to pre-install Java and the firmware application (ccb_connect.exe). Hence, the teacher has to give a prior explanation or tutorial to students. Second, common-coding builder for computers only works online. For students who work in inadequate internet facilities, it may become an issue."

Using Arduino and Online Block-Structured Programing Language for Physics Practical Work

Abstract

Distance learning in physics is still facing challenges, mainly due to the difficult access to a laboratory for practical work. Practical work is an essential part of the physics classroom because it allows students to interact with authentic physics phenomena and develop their scientific abilities. In this paper, we propose alternative experiments that can be carried out at home with affordable apparatus. We explain the use of Arduino UNO board and block-structured programming environment to design physics experiments about investigating light-emitting diode (LED) and capacitor characteristics. Block-structured programming in the common-coding builder is used because it has extension features such as plotting data in a graph directly and programming the Arduino board. Moreover, a user with no prior knowledge of programming can use it easily.

Keywords: Arduino, physics, practical work, block-structured programming, distance learning

1. Introduction

In the past, the distance learning mode's main obstacle was the lack of interaction among students and teachers. The advanced communication technology that we have nowadays has a significant impact on the distance learning process. The interaction among students and teachers during distance learning has been tremendously enhanced by various communication platform and learning management system. However, teaching physics in distance learning mode is still challenging.

Practical work plays an essential role in physics education to develop students' scientific ability, understand the process of scientific investigation, and connect the real physical world with theory [1–3]. The challenge for physics education in distance learning mode is bringing students to experience laboratory work effectively and safely. There are some alternatives for this challenge, including using computer simulations and portable experiment kits [4,5]. Computer simulation may engage students in scientific processes such as manipulating variables, observing phenomena, and analyzing the relationship among variables. However, it cannot bring authentic laboratory experience. Students can physically work on objects, practice using instruments safely, be aware of real measurement uncertainty, observe the real phenomena, and create conceptual models of the physical world.

Students may perform laboratory work at home by using an experiment kit. There are various experiment kits in the market, but they are mostly pricy and only can be used for specific experiment topics. However, the recent development of low-cost microcontrollers and sensors offers feasibility in bringing affordable physics experiment tools for distance learning [6].

Arduino is a low-cost microcontroller that has been widely used for physics education [7–10]. It can be connected with various sensors to measure a lot of physical quantity [8,11,12]. Usually, Arduino programing use C or C++ programming language. However, it might be difficult for a teacher to implement the programing language in the physics classroom because students may not have prior knowledge about computer programming[13]. Fortunately, a user-friendly programming environment, called block-structured programming language, can be used to program Arduino. In a block-structured programming language, the developer only needs to drag and drop the blocks to construct a program, and they do not have to memorize the syntax to write the code.

This paper shows the use of Arduino and block-structured programming language provided in common-coding builder[14] for a didactic physics experiment about investigating capacitor and LED characteristics. Common-coding builder is based on Scratch, a widely-used block-structured programming language in STEM education[15]. However, the common-coding builder offers extension features such as chart, google sheet, and Arduino programming. Those features are useful for setting up physics experiments with Arduino, getting and analyzing the data.

2. Investigating The Characteristic of LED

2.1 Hardware Set-Up

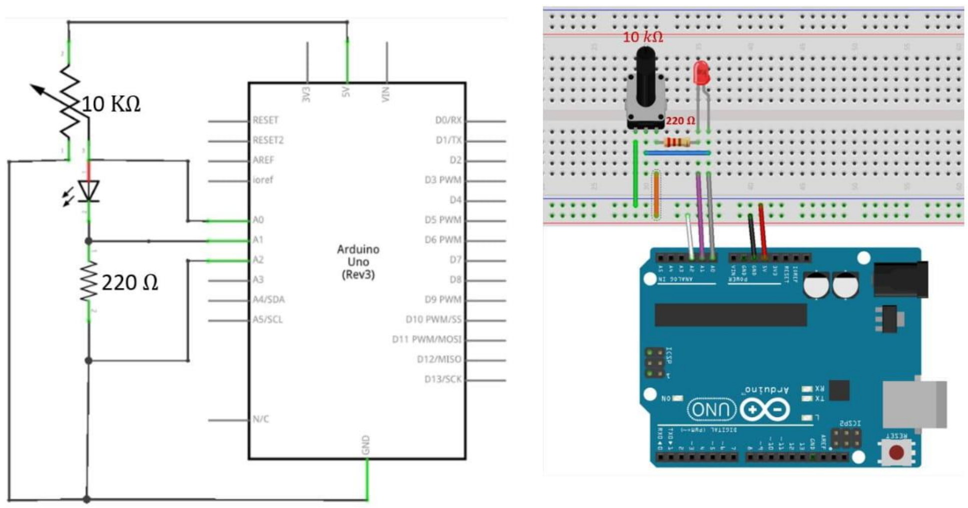

Figure 1. The circuit used in the experiment to investigate the characteristic of LED

In this experiment, the apparatus consists of an Arduino UNO board, a USB serial cable, LEDs, a 220 Ω resistor, a $10k\Omega$ potentiometer, a breadboard, a computer with Windows operating system (OS), and internet connection. The circuit diagram to investigate the characteristic of LED is shown in Figure 1a. In this set-up, Arduino UNO is used as a voltage source, a current, and a voltage sensor. A potentiometer is used as a voltage divider. By adjusting the potentiometer, we can change the voltage across LED, and then measure the current.

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The code to program Arduino UNO in investigating the characteristic of LED is shown in Figure 4. In this set-up, voltage and current are measured from the value recorded by the analog pin of Arduino UNO.

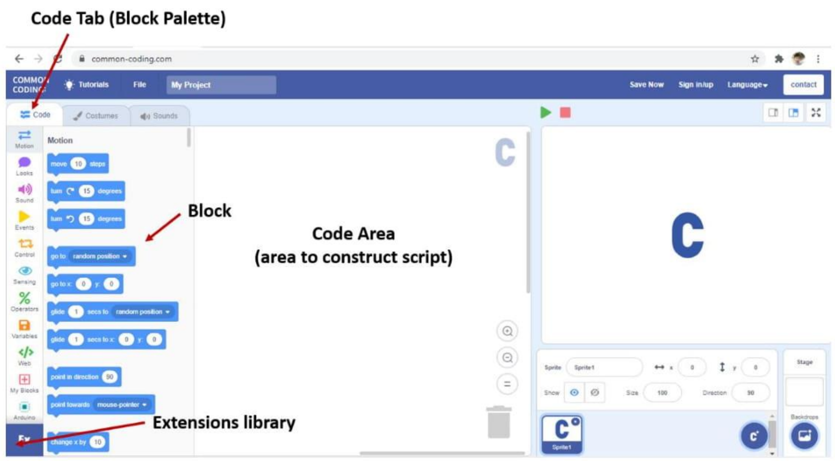

Figure 2. The layout of common-coding builder

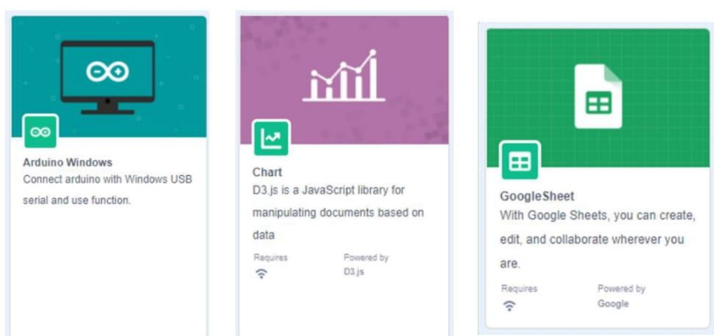

Figure 3. Some extensions library in common-coding builder, i.e. Arduino Windows, Chart, and Google Sheet

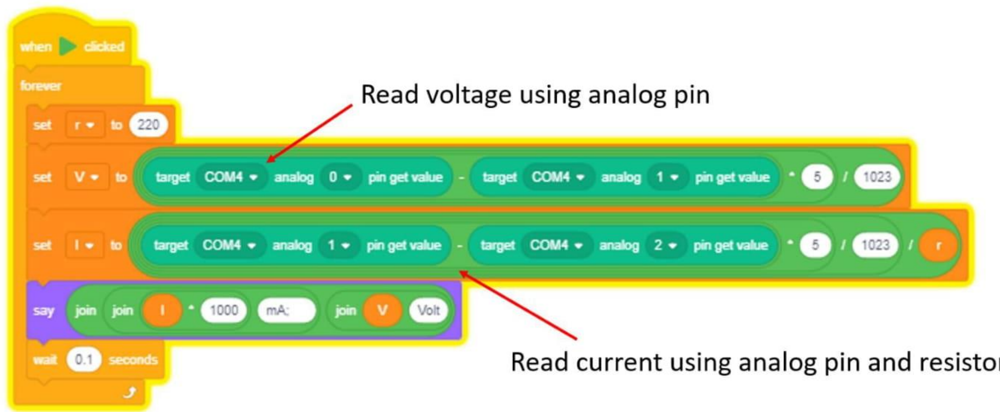

Figure 4. The code for investigating LED characteristic using the common-coding builder environment

2.3 Discussion

Typically, LED consists of semiconductors materials which has an energy bandgap. Enough applied voltage can cause electrons to jump from one material to another. The electron transition from the conduction to the valence band causes light-emitting. The voltage at which the first transition occurs is called threshold voltage. The first transition can be observed from the first light emitted or the first current measured in the circuit. The energy band gap of each LED can then be calculated with the equation (1). Each type of LED is fabricated from various semiconductor materials; thus, they have various energy bandgap. Different semiconductor materials will produce multiple colors.

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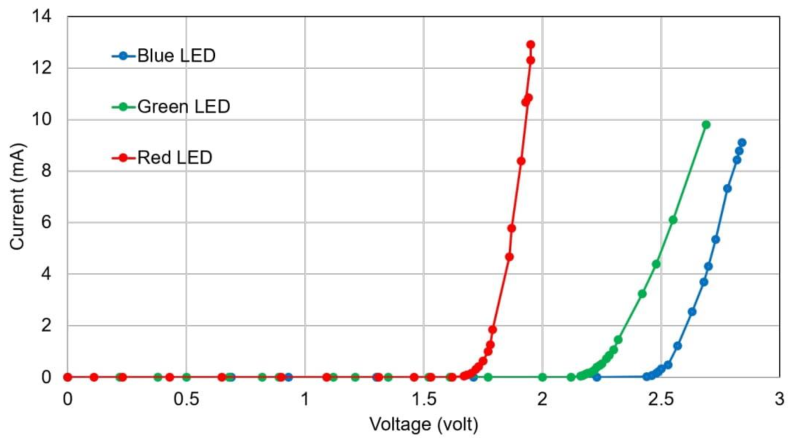

Figure 5. Voltage-current relationship in red, green, and blue LED at room temperature

In this experiment, we investigate the voltage-current relationship in red, green, and blue LEDs. As shown in Figure 5, for low applied voltage, current cannot flow through the LED. After the applied voltage is surpassing a specific threshold voltage, the current starts to flow. Table 1 presents the measured threshold voltage. Current in red LED starts to flow when the applied voltage is around 1.67 V. For green LED, the applied voltage should be higher than 2.16 V to allow current flow. Meanwhile, the blue LED requires the highest applied voltage, i.e., 2.46 V, to allow current flow.

The experiment may help students to understand how circuit with LED works. It also can introduce the quantum properties of solids to students. Furthermore, this experiment can be extended with more colors of LED for determining the Planck constant value[16].

Table 1. The energy band gap of various color LED

LED	$V_{threshold}$ (eV)	E_{gap} (eV)
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Green	2.16	2.16
Blue	2..46	2..46

3. Investigating Capacitor

3.1 Hardware set-up

The purpose of the 'investigating capacitor' experiment is to plot the capacitor voltage as a function of time during the charging and discharging process. The equipment consists of an Arduino Uno board, a USB-serial cable, a capacitor, a voltage sensor, a resistor, a breadboard, jumper wires, a computer with Windows operating system, and an internet connection. The voltage sensor is not compulsory; we can use an Arduino board to read the voltage as long as the measured voltage is less than 5V (See Supporting Information). The equipment set-up is presented in Figure 6. In this set-up, a digital pin of Arduino Uno is used as a voltage output because it can be easily switched ON for charging the capacitor and switched OFF for discharging the capacitor.

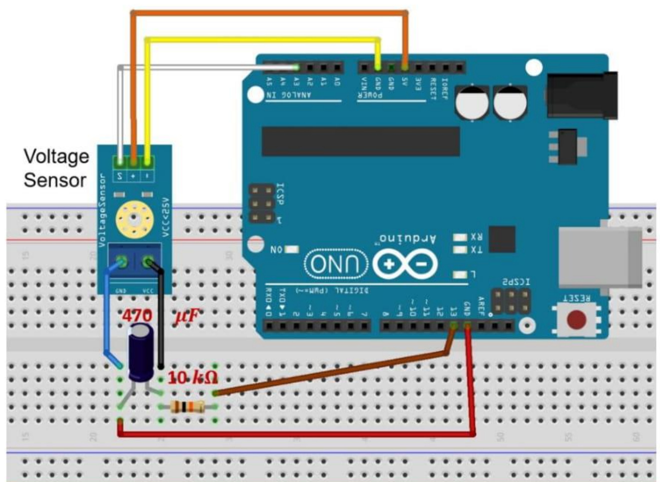

Figure 6. 'Investigating Capacitor' Experiment Set-up

3.2 Programing

The code used for charging and discharging capacitor is presented in Figure 7 and 8, respectively. During the charging process, the digital pin output is set as 1 (HIGH) for supplying voltage. Meanwhile, when discharging cycle, the digital pin output is set as 0 (LOW) to cut the voltage supply.

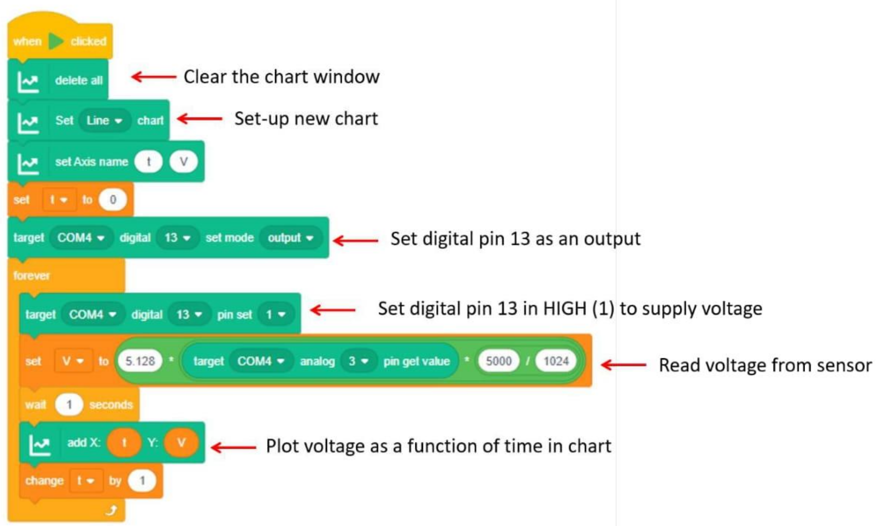

Figure 7. Code for investigating time-varying capacitor voltage during charging process

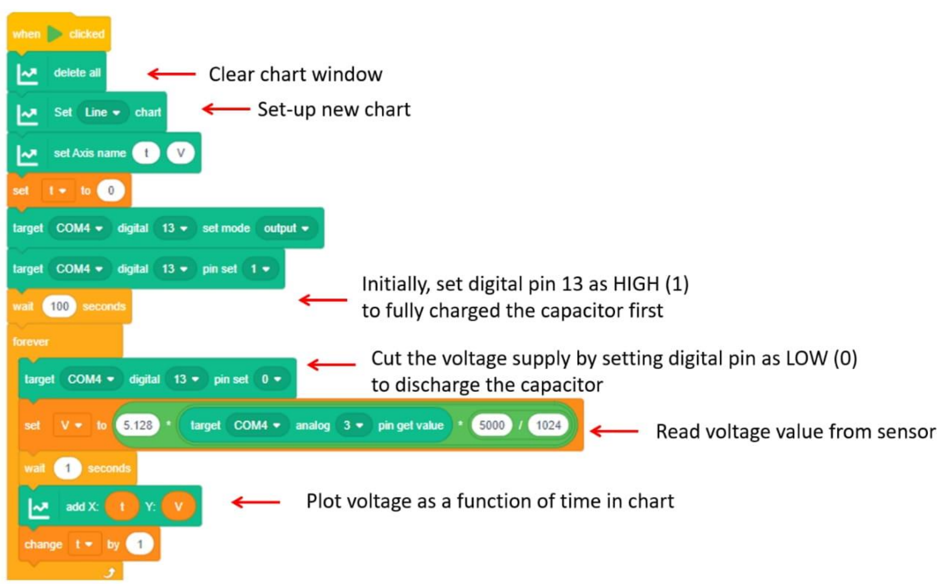

Figure 8. Code for investigating time-varying capacitor voltage during discharging process

3.3 Discussions

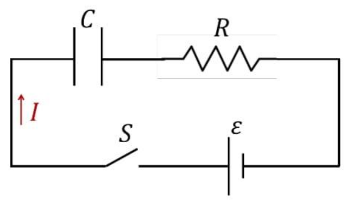

Figure 9. Basic circuit for 'investigating capacitor' experiment

The basic diagrammatic circuit for the charging capacitor can be seen in Figure 9. When a voltage source is connected to the capacitor and the resistor, analysis with Kirchhoff rule will give:

$$\varepsilon - \frac{q}{C} - IR = 0 \qquad (2)$$

Where ε is the voltage source, IR is the voltage across the resistor, and $\frac{q}{C}$ is the voltage across the capacitor. By substitute $I = \frac{dq}{dt}$ and dividing all terms by R, Eq. 1 can be written as:

$$\frac{\varepsilon}{R} - \frac{q}{RC} - \frac{dq}{dt} = 0$$

$$\frac{dq}{dt} = -\frac{q - C\varepsilon}{RC} \qquad (3)$$

By solving Eq. 3 and using an assumption that the capacitor is initially discharged, we can yield charge in the capacitor as a function of time, i.e.:

$$q(t) = C\varepsilon\left(1 - e^{-\frac{t}{RC}}\right) \qquad (4)$$

Since $V = q/C$, the voltage across the capacitor, $V_c(t)$ can be expressed as:

$$V_c(t) = \varepsilon\left(1 - e^{-\frac{t}{RC}}\right) \qquad (5)$$

When the voltage source is disconnected, the capacitor will discharge. Analysis with Kirchhoff rule will give:

$$-\frac{q}{C} - IR = 0 \qquad (6)$$

We can model the voltage across the capacitor during the discharge process within the same procedure as the analysis for capacitor charging. The voltage across capacitor during the discharging process can be modeled in Eq. 7.

$$V_c(t) = \varepsilon \exp\left(-\frac{t}{RC}\right) \qquad (7)$$

With the Arduino and common-coding builder software, voltage across the capacitor during the charge and discharge process has been measured real-time and directly plotted in graphs,

such as depicted in figures 10 and 11. Figure 10 shows the voltage as a function of time during the charging process. Initially, the capacitor voltage increases fast; then, the increment becomes slower until it reaches a steady maximum voltage. This result is in agreement with the theory presented in Eq. 5. Figure 11 shows the voltage-time graph when the capacitor is discharged. As predicted theoretically in Eq. 7, the experiment showed that the capacitor voltage decreases exponentially during the discharging process.

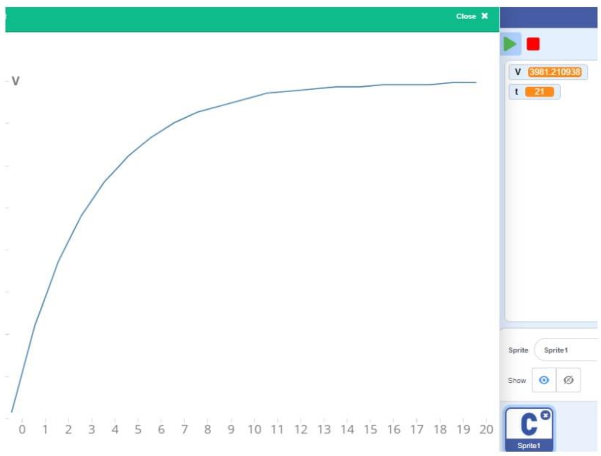

Figure 10. The time-varying voltage across capacitor during charging process presented in chart window available in common-coding builder. Voltage and time are in volt and second, respectively.

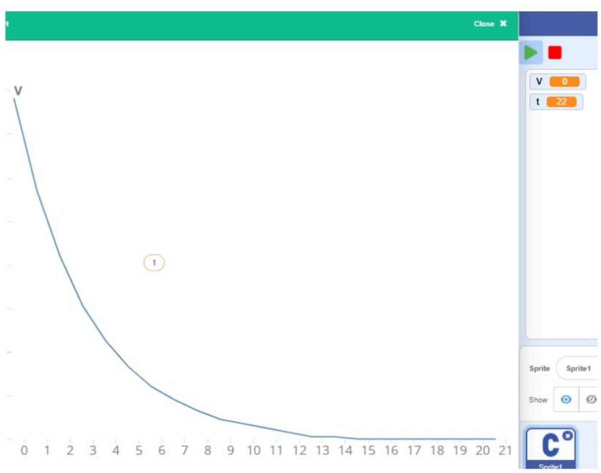

Figure 11. The time-varying voltage across capacitor during discharging process presented in chart window available in common-coding builder. Voltage and time are in volt and second, respectively.

Data visualization in the common-coding builder helps students understand physical phenomena with graph representation and connect experimental results with theoretical models. Moreover, with minimal knowledge of computer programming, students can do the activities at home. Although common-coding builder has advantages such as introducing a foundation of computational thinking to students with minimal knowledge of programming, it has several limitations. First, to connect the common-coding builder to Arduino UNO, we need to pre-install Java and the firmware application (ccb_connect.exe). Hence, the teacher has to give a prior explanation or tutorial to students. Second, common-coding builder for computers only works online. For students who work in inadequate internet facilities, it may become an issue.

4. Conclusion

Arduino and block-structured language programing, like common-coding builders, can be used to design various experiments to support physics learning. The apparatus is affordable, and the programming can be done easily by students who do not have prior knowledge of coding a program. Teachers can design experiments with various topics and assign students to try them at home. Since access to a laboratory is difficult for physics distance learning, this experiment can become an alternative to training students' practical skills, science process skills, and computational thinking skills. During a difficult time, such as the COVID-19 pandemic, it may be useful to support high school students or early year college students exploring physics from home.

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Gmail **Elisabeth Founda <elisa.founda@gmail.com>**

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1 message

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Re: "Using Arduino and Online Block-Structured Programing Language for Physics Practical Work"
Article reference: PED-102718.R1

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4. Bukti hasil review kedua 6 Mei 2021

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We have now received the referee report on your Paper, which is being considered by Physics Education.

The referee has a further issue which we would be grateful if you could respond to if possible. Their comments are below this email, but may not require further revision.

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COMMENTS TO THE AUTHOR(S)
Many thanks for the changes. I have still not managed to get the code to work, however I am using Windows 10 on an older computer and for whatever reason, it doesn't seem to like the block language interface. Refusing to download the code to the UNO.

Letter reference: DRWMi01

5. Bukti submit revisi kedua 12 Mei 2021

LIST OF CHANGES IN THE REVISED MANUSCRIPT

We made appropriate changes as described below:

1. We changed the first paragraph in 2.2 to:

   To program Arduino UNO for a voltage source, a current, and a voltage sensor, we have to program it through the common-codding builder. Common-coding builder can be accessed online using Microsoft edge or Google Chrome browser in https://common-coding.com/. To allow Arduino programming, we need to choose Arduino Windows extension; after that, download and run firmware to connect the Arduino Uno hardware to the software. The firmware application, ccb_connect.exe, is running in a Java environment. The complete procedure to allow connection between Arduino UNO and the common-coding builder for the first time is explained in the Supporting Material. As a disclaimer, we test the common-coding builder in the Windows OS environment only due to the limitation of devices. However, the common-coding builder also provides features for Mac OS.

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2. We removed figure 2 and 3
3. We edited the figure number in the whole manuscript

   Note: all the changes are marked with orange color.

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Elisabeth Pratidhina[a,b], Dadan Rosana[a], Heru Kuswanto[a], Wipsar Sunu Brams Dwandaru[a]

[a] Universitas Negeri Yogyakarta, Jl. Colombo No. 1, Karang Malang, Caturtunggal, Depok, Sleman, Daerah Istimewa Yogykarta 55281.

[b] Department of Physics Education, Widya Mandala Catholic University Surabaya, Jl. Kalijudan 37 Surabaya 60114

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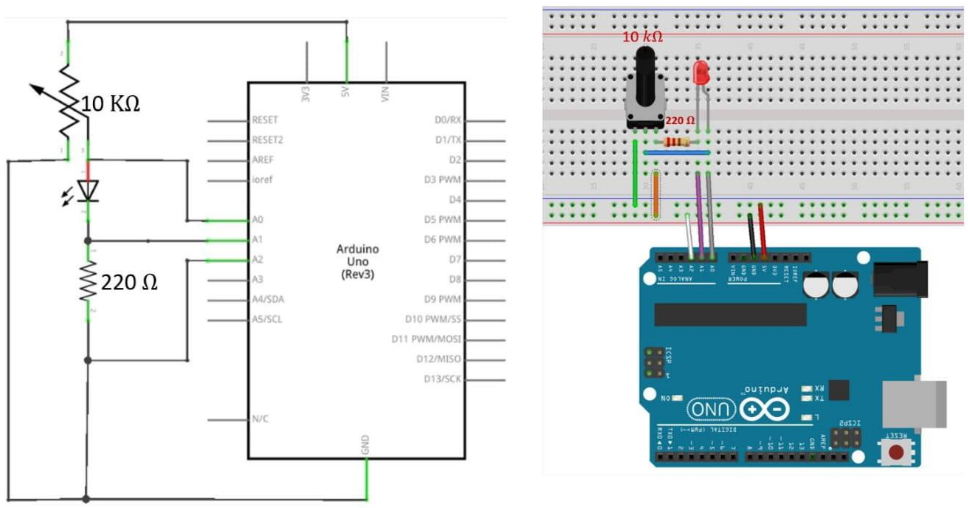

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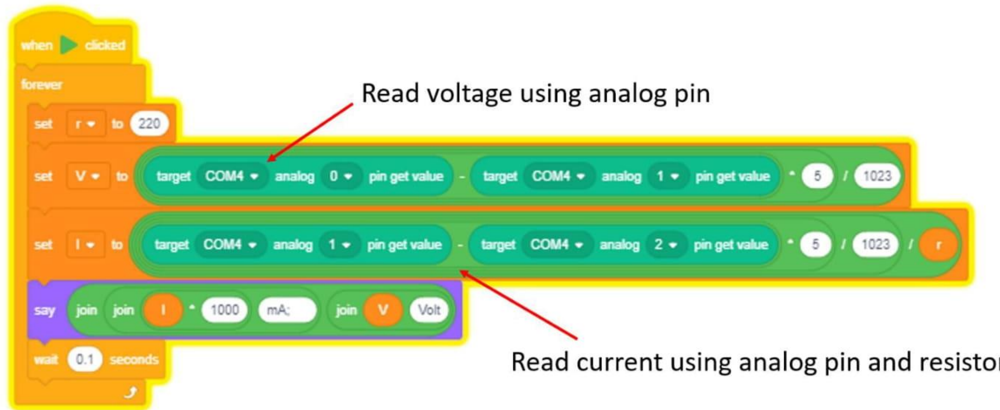

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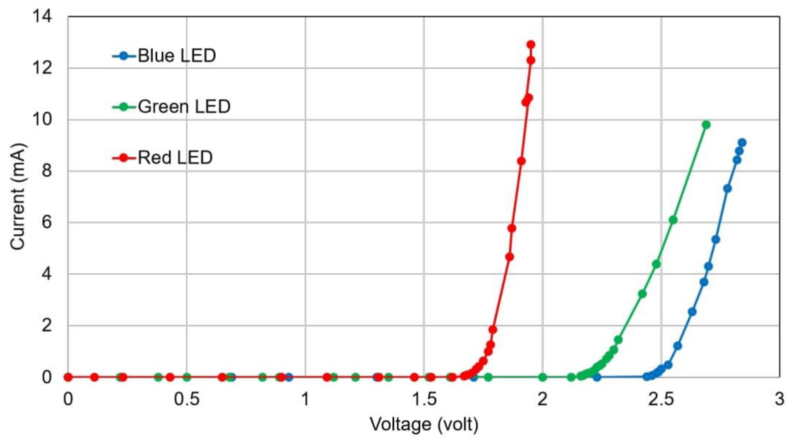

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3. Investigating Capacitor

3.1 Hardware set-up

The purpose of the 'investigating capacitor' experiment is to plot the capacitor voltage as a function of time during the charging and discharging process. The equipment consists of an Arduino Uno board, a USB-serial cable, a capacitor, a voltage sensor, a resistor, a breadboard, jumper wires, a computer with Windows operating system, and an internet connection. The voltage sensor is not compulsory; we can use an Arduino board to read the voltage as long as the measured voltage is less than 5V. The equipment set-up is presented in Figure 4. In this set-up, a digital pin of Arduino Uno is used as a voltage output because it can be easily switched ON for charging the capacitor and switched OFF for discharging the capacitor.

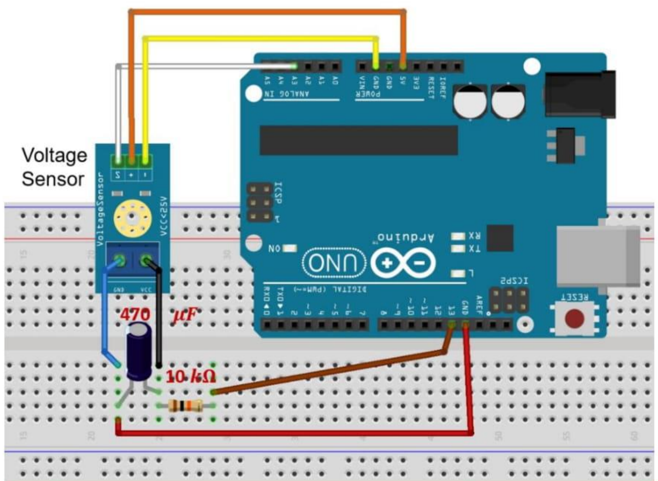

Figure 4. 'Investigating Capacitor' Experiment Set-up

3.2 Programing

The code used for charging and discharging capacitor is presented in Figure 5 and 6, respectively. During the charging process, the digital pin output is set as 1 (HIGH) for supplying voltage. Meanwhile, when discharging cycle, the digital pin output is set as 0 (LOW) to cut the voltage supply.

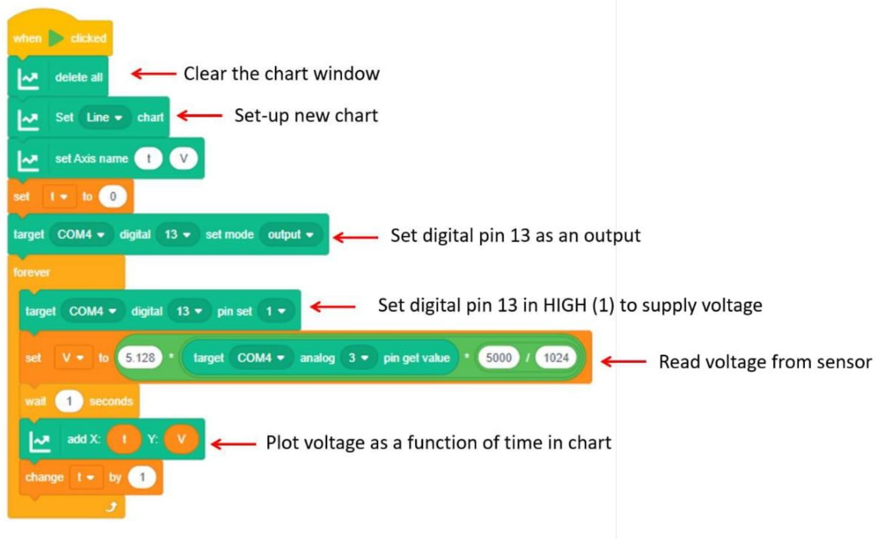

Figure 5. Code for investigating time-varying capacitor voltage during charging process

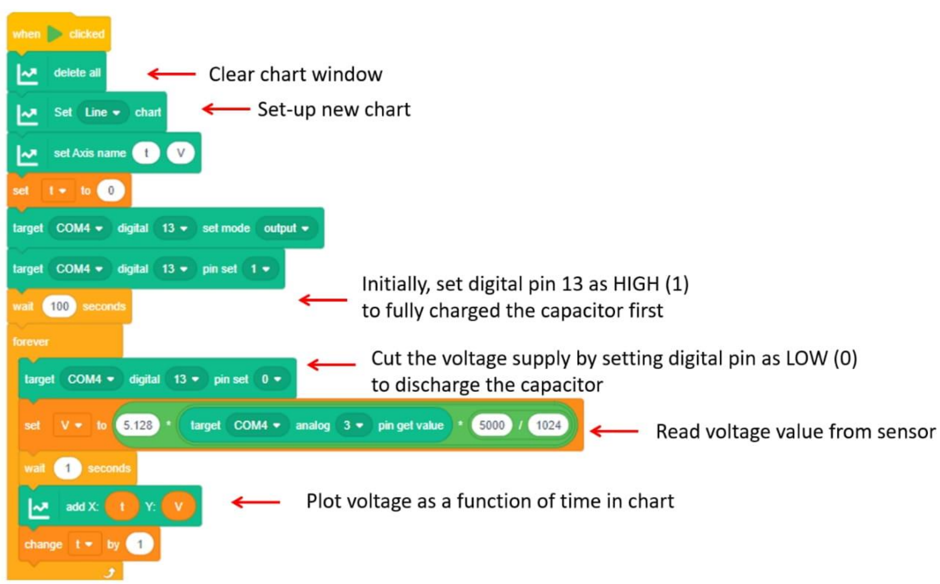

Figure 6. Code for investigating time-varying capacitor voltage during discharging process

3.3 Discussions

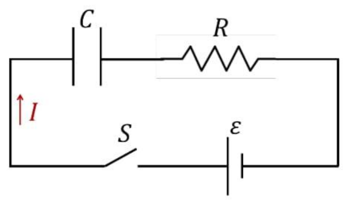

Figure 7. **Basic circuit for 'investigating capacitor' experiment**

The basic diagrammatic circuit for the charging capacitor can be seen in Figure 7. When a voltage source is connected to the capacitor and the resistor, analysis with Kirchhoff rule will give:

$$\varepsilon - \frac{q}{C} - IR = 0 \qquad (2)$$

Where ε is the voltage source, IR is the voltage across the resistor, and $\frac{q}{C}$ is the voltage across the capacitor. By substitute $I = \frac{dq}{dt}$ and dividing all terms by R, Eq. 1 can be written as:

$$\frac{\varepsilon}{R} - \frac{q}{RC} - \frac{dq}{dt} = 0$$

$$\frac{dq}{dt} = -\frac{q - C\varepsilon}{RC} \qquad (3)$$

By solving Eq. 3 and using an assumption that the capacitor is initially discharged, we can yield charge in the capacitor as a function of time, i.e.:

$$q(t) = C\varepsilon\left(1 - e^{-\frac{t}{RC}}\right) \qquad (4)$$

Since $V = q/C$, the voltage across the capacitor, $V_c(t)$ can be expressed as:

$$V_c(t) = \varepsilon\left(1 - e^{-\frac{t}{RC}}\right) \qquad (5)$$

When the voltage source is disconnected, the capacitor will discharge. Analysis with Kirchhoff rule will give:

$$-\frac{q}{C} - IR = 0 \qquad (6)$$

We can model the voltage across the capacitor during the discharge process within the same procedure as the analysis for capacitor charging. The voltage across capacitor during the discharging process can be modeled in Eq. 7.

$$V_c(t) = \varepsilon \exp\left(-\frac{t}{RC}\right) \qquad (7)$$

With the Arduino and common-coding builder software, voltage across the capacitor during the charge and discharge process has been measured real-time and directly plotted in graphs,

such as depicted in figures 8 and 9. Figure 8 shows the voltage as a function of time during the charging process. Initially, the capacitor voltage increases fast; then, the increment becomes slower until it reaches a steady maximum voltage. This result is in agreement with the theory presented in Eq. 5. Figure 9 shows the voltage-time graph when the capacitor is discharged. As predicted theoretically in Eq. 7, the experiment showed that the capacitor voltage decreases exponentially during the discharging process.

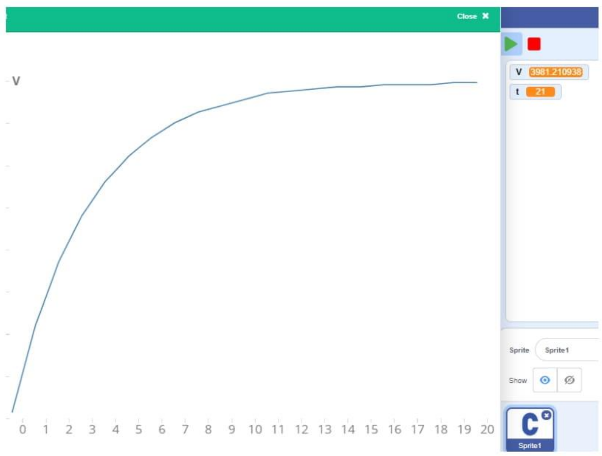

Figure 8. **The time-varying voltage across capacitor during charging process presented in chart window available in common-coding builder. Voltage and time are in volt and second, respectively.**

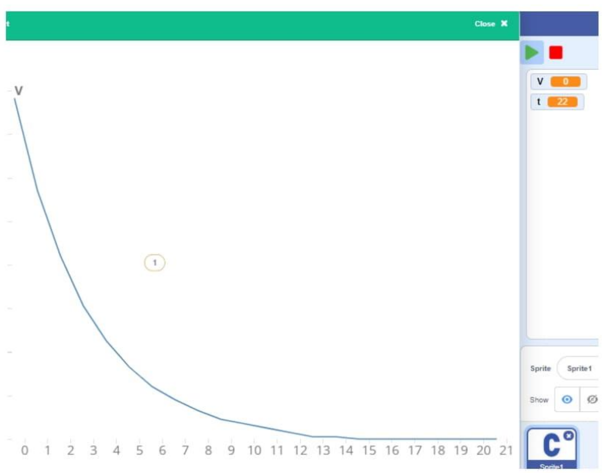

Figure 9. **The time-varying voltage across capacitor during discharging process presented in chart window available in common-coding builder. Voltage and time are in volt and second, respectively.**

Data visualization in the common-coding builder helps students understand physical phenomena with graph representation and connect experimental results with theoretical models. Moreover, with minimal knowledge of computer programming, students can do the activities at home. Although common-coding builder has advantages such as introducing a foundation of computational thinking to students with minimal knowledge of programming, it has several limitations. First, to connect the common-coding builder to Arduino UNO, we need to pre-install Java and the firmware application (ccb_connect.exe). Hence, the teacher has to give a prior explanation or tutorial to students. Second, common-coding builder for computers only works online. For students who work in inadequate internet facilities, it may become an issue.

4. Conclusion

Arduino and block-structured language programing, like common-coding builders, can be used to design various experiments to support physics learning. The apparatus is affordable, and the programming can be done easily by students who do not have prior knowledge of coding a program. Teachers can design experiments with various topics and assign students to try them at home. Since access to a laboratory is difficult for physics distance learning, this experiment can become an alternative to training students' practical skills, science process skills, and computational thinking skills. During a difficult time, such as the COVID-19 pandemic, it may be useful to support high school students or early year college students exploring physics from home.

5. Acknowledgments

The authors would like to thank Ministry of Research and Technology and Ministry of Education and Culture of Republic of Indonesia

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Q4 **and Wipsar Sunu Brams Dwandaru[1]**

[1] Universitas Negeri Yogyakarta, Jl. Colombo No. 1, Karang Malang, Caturtunggal,
Q5 Depok, Sleman, Daerah Istimewa Yogykarta 55281
[2] Department of Physics Education, Widya Mandala Catholic University Surabaya, Jl. Kalijudan 37, Surabaya 60114

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Abstract

Distance learning in physics is still facing challenges, mainly due to the difficult access to a laboratory for practical work. Practical work is an essential part of the physics classroom because it allows students to interact with authentic physics phenomena and develop their scientific abilities. In this paper, we propose alternative experiments that can be carried out at home with affordable apparatus. We explain the use of Arduino UNO board and block-structured programming environment to design physics experiments about investigating light-emitting diode and capacitor characteristics. Block-structured programming in the common-coding builder is used because it has extension features such as plotting data in a graph directly and programming the Arduino board. Moreover, a user with no prior knowledge of programming can use it easily.

Keywords: Arduino, physics, practical work, block-structured programming, distance learning

Q7 Supplementary material for this article is available online

1. Introduction

In the past, the distance learning mode's main obstacle was the lack of interaction among students and teachers. The advanced communication technology that we have nowadays has a significant impact on the distance learning process. The interaction among students and teachers during distance learning has been tremendously enhanced by various communication platform and learning management system. However, teaching physics in distance learning mode is still challenging.

Practical work plays an essential role in physics education to develop students' scientific ability, understand the process of scientific investigation, and connect the real physical world with theory [1–3]. The challenge for physics education in distance learning mode is bringing students to experience laboratory work effectively and safely. There are some alternatives for this challenge, including using computer simulations and portable experiment kits [4, 5]. Computer simulation may engage students in scientific processes such as manipulating variables, observing phenomena, and analysing the relationship among variables. However, it cannot bring authentic laboratory experience. Students can physically work on objects, practice using instruments safely, be aware of real measurement uncertainty, observe the real phenomena, and create conceptual models of the physical world.

Students may perform laboratory work at home by using an experiment kit. There are various experiment kits in the market, but they are mostly pricy and only can be used for specific experiment topics. However, the recent development of low-cost microcontrollers and sensors offers feasibility in bringing affordable physics experiment tools for distance learning [6].

Arduino is a low-cost microcontroller that has been widely used for physics education [7–10]. It can be connected with various sensors to measure a lot of physical quantity [8, 11, 12]. Usually, Arduino programing use C or C++ programming language. However, it might be difficult for a teacher to implement the programming language in the physics classroom because students may not have prior knowledge about computer programming [13]. Fortunately, a user-friendly programming environment, called block-structured programming language, can be used to program Arduino. In a block-structured programming language, the developer only needs to drag and drop the blocks to construct a program, and they do not have to memorise the syntax to write the code.

This paper shows the use of Arduino and block-structured programming language provided in common-coding builder [14] for a didactic physics experiment about investigating capacitor and light-emitting diode (LED) characteristics. Common-coding builder is based on Scratch, a widely used block-structured programming language in STEM education [15]. However, the common-coding builder offers extension features such as chart, Google Sheet, and Arduino programming. Those features are useful for setting up physics experiments with Arduino, getting and analysing the data.

2. Investigating the characteristic of LED

2.1. Hardware set-up

In this experiment, the apparatus consists of an Arduino UNO board, a USB serial cable, LEDs, a 220 Ω resistor, a 10kΩ potentiometer, a breadboard, a computer with Windows operating system (OS), and internet connection. The circuit diagram to investigate the characteristic of LED is shown in figure 1(a). In this set-up, Arduino UNO is used as a voltage source, a current, and a voltage sensor. A potentiometer is used as a voltage divider. By adjusting the potentiometer, we can change the voltage across LED, and then measure the current. Q8

2.2. Programing

To program Arduino UNO for a voltage source, a current, and a voltage sensor, we have to program it through the common-codding builder. Common-coding builder can be accessed online using a browser in https://common-coding.com/. The initial layout is presented in figure 2. To allow Arduino programming, we need to choose Arduino Windows extension (see figure 3); after that, download and run firmware to connect the Arduino Uno hardware to the software. The firmware application, ccb_connect.exe, is running in a Java environment. The complete procedure to allow connection between Arduino UNO and the common-coding builder for the first time is explained in the supporting information (available online at stacks.iop.org/PED/00/00000/mmedia). As a disclaimer, we test the common-coding builder in the Windows OS environment only due to the limitation of devices. However, the common-coding builder also provides features for Mac OS.

The code to program Arduino UNO in investigating the characteristic of LED is shown in figure 4. In this set-up, voltage and current are

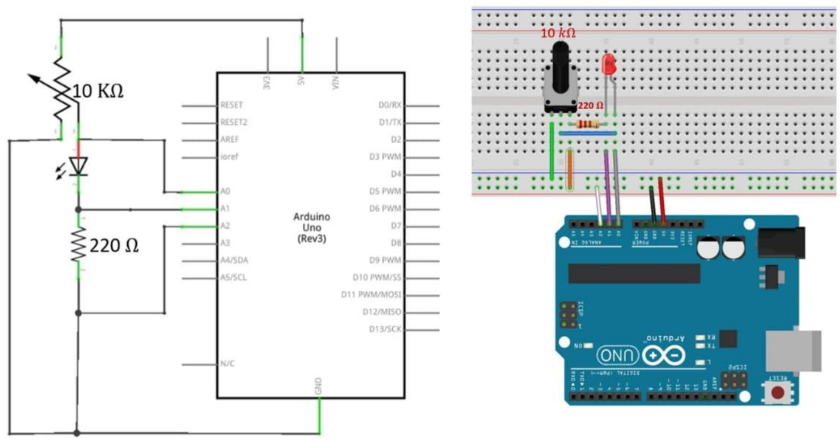


Figure 1. The circuit used in the experiment to investigate the characteristic of LED.

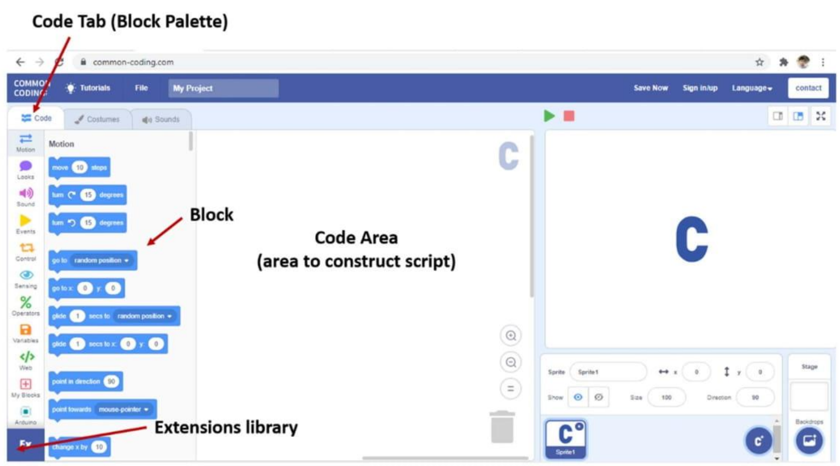


Figure 2. The layout of common-coding builder.

measured from the value recorded by the analog pin of Arduino UNO.

2.3. Discussion

Typically, LED consists of semiconductors materials which has an energy bandgap. Enough applied voltage can cause electrons to jump from one material to another. The electron transition from the conduction to the valence band causes light-emitting. The voltage at which the first transition occurs is called threshold voltage. The first transition can be observed from the first light emitted or the first current measured in the circuit. The

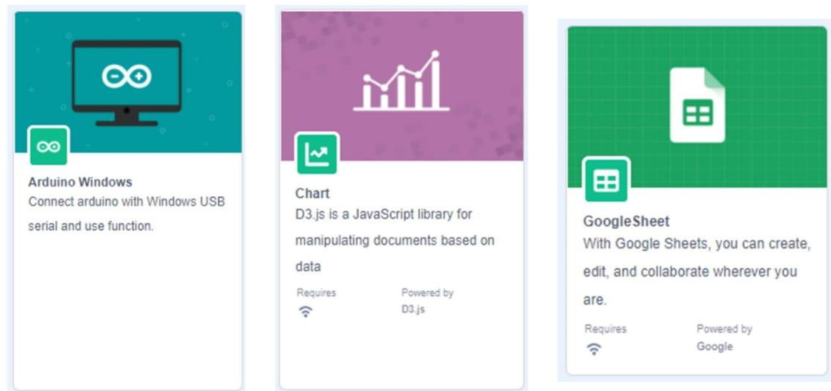


Figure 3. Some extensions library in common-coding builder, i.e. Arduino Windows, chart, and Google Sheet.

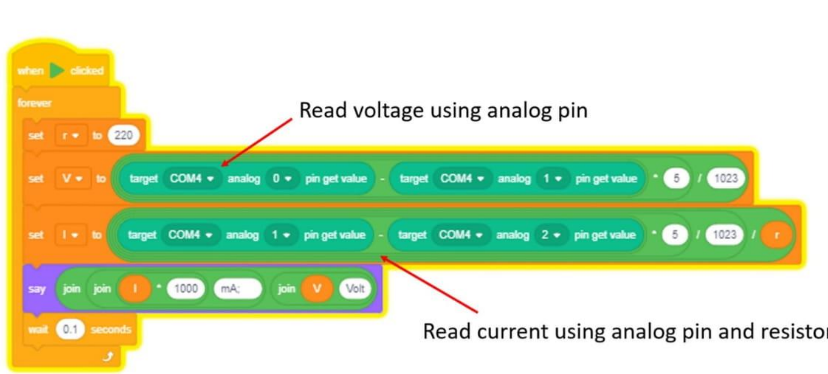


Figure 4. The code for investigating LED characteristic using the common-coding builder environment.

energy band gap of each LED can then be calculated with the equation (1). Each type of LED is fabricated from various semiconductor materials; thus, they have various energy bandgap. Different semiconductor materials will produce multiple colours

$$E_{\text{gap}} = eV_{\text{threshold}}. \quad (1)$$

In this experiment, we investigate the voltage–current relationship in red, green, and blue LEDs. As shown in figure 5, for low applied voltage, current cannot flow through the LED. After the applied voltage is surpassing a specific threshold voltage, the current starts to flow. Table 1 presents the measured threshold voltage. Current in red LED starts to flow when the applied voltage is around 1.67 V. For green LED, the applied voltage should be higher than 2.16 V to allow current flow. Meanwhile, the blue LED requires the highest applied voltage, i.e. 2.46 V, to allow current flow.

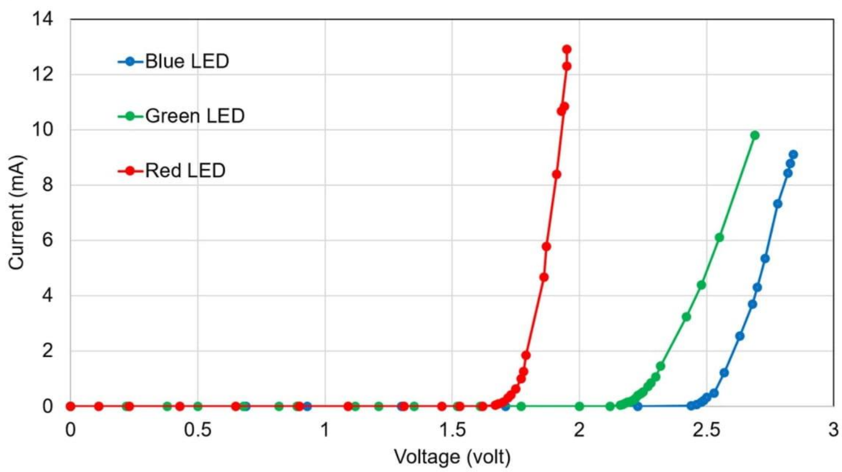


Figure 5. Voltage–current relationship in red, green, and blue LED at room temperature.

Table 1. The energy band gap of various colour LED.

LED	$V_{threshold}$ (eV)	E_{gap} (eV)
Red	1.67	1.67
Green	2.16	2.16
Blue	2.46	2.46

The experiment may help students to understand how circuit with LED works. It also can introduce the quantum properties of solids to students. Furthermore, this experiment can be extended with more colours of LED for determining the Planck constant value [16].

3. Investigating capacitor

3.1. Hardware set-up

The purpose of the 'investigating capacitor' experiment is to plot the capacitor voltage as a function of time during the charging and discharging process. The equipment consists of an Arduino Uno board, a USB-serial cable, a capacitor, a voltage sensor, a resistor, a breadboard, jumper wires, a computer with Windows OS, and an internet connection. The voltage sensor is not compulsory; we can use an Arduino board to read the voltage as long as the measured voltage is less than 5 V (see supporting information). The equipment set-up is presented in figure 6. In this set-up, a digital pin of Arduino Uno is used as a voltage output because it can be easily switched ON for charging the capacitor and switched OFF for discharging the capacitor.

3.2. Programing

The code used for charging and discharging capacitor is presented in figures 7 and 8, respectively. During the charging process, the digital pin output is set as 1 (HIGH) for supplying voltage. Meanwhile, when discharging cycle, the digital pin output is set as 0 (LOW) to cut the voltage supply.

3.3. Discussions

The basic diagrammatic circuit for the charging capacitor can be seen in figure 9. When a voltage source is connected to the capacitor and the resistor, analysis with Kirchhoff rule will give:

$$\varepsilon - \frac{q}{C} - IR = 0 \qquad (2)$$

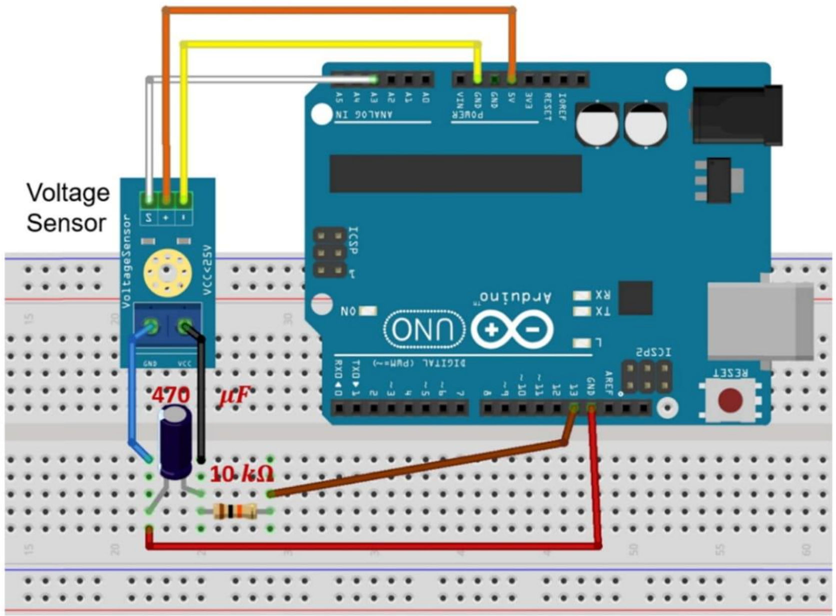


Figure 6. 'Investigating capacitor' experiment set-up.

where ε is the voltage source, IR is the voltage across the resistor, and $\frac{q}{C}$ is the voltage across the capacitor. By substitute $I = \frac{\mathrm{d}q}{\mathrm{d}t}$ and dividing all terms by R, equation (1) can be written as:

$$\begin{gathered}\frac{\varepsilon}{R} - \frac{q}{RC} - \frac{\mathrm{d}q}{\mathrm{d}t} = 0 \\ \frac{\mathrm{d}q}{\mathrm{d}t} = -\frac{q - C\varepsilon}{RC}\end{gathered}. \qquad (3)$$

By solving equation (3) and using an assumption that the capacitor is initially discharged, we can yield charge in the capacitor as a function of time, i.e.:

$$q(t) = C\varepsilon\left(1 - \mathrm{e}^{-\frac{t}{RC}}\right). \qquad (4)$$

Since $V = q/C$, the voltage across the capacitor, $V_{\mathrm{c}}(t)$ can be expressed as:

$$V_{\mathrm{c}}(t) = \varepsilon\left(1 - \mathrm{e}^{-\frac{t}{RC}}\right). \qquad (5)$$

When the voltage source is disconnected, the capacitor will discharge. Analysis with Kirchhoff rule will give:

$$-\frac{q}{C} - IR = 0. \qquad (6)$$

We can model the voltage across the capacitor during the discharge process within the same procedure as the analysis for capacitor charging. The voltage across capacitor during the discharging process can be modelled in equation (7)

$$V_{\mathrm{c}}(t) = \varepsilon \exp\left(-\frac{t}{RC}\right). \qquad (7)$$

With the Arduino and common-coding builder software, voltage across the capacitor during the charge and discharge process has been measured real-time and directly plotted in graphs, such as depicted in figures 10 and 11. Figure 10 shows the voltage as a function of time during the charging process. Initially, the capacitor voltage increases

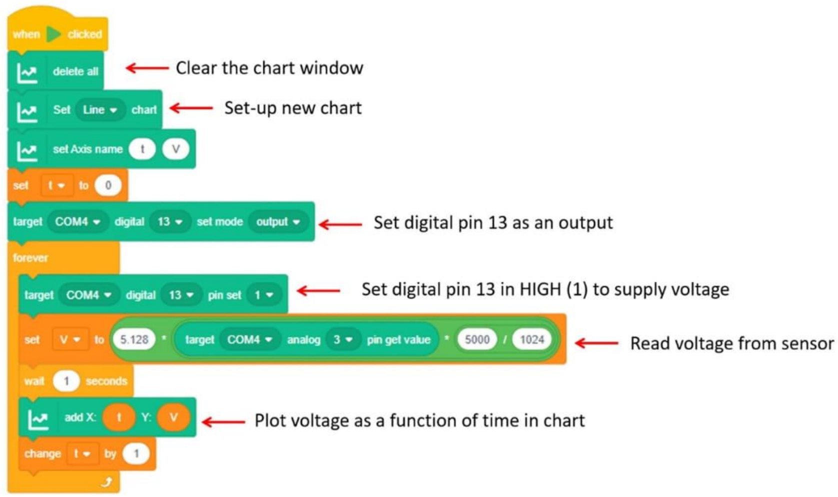
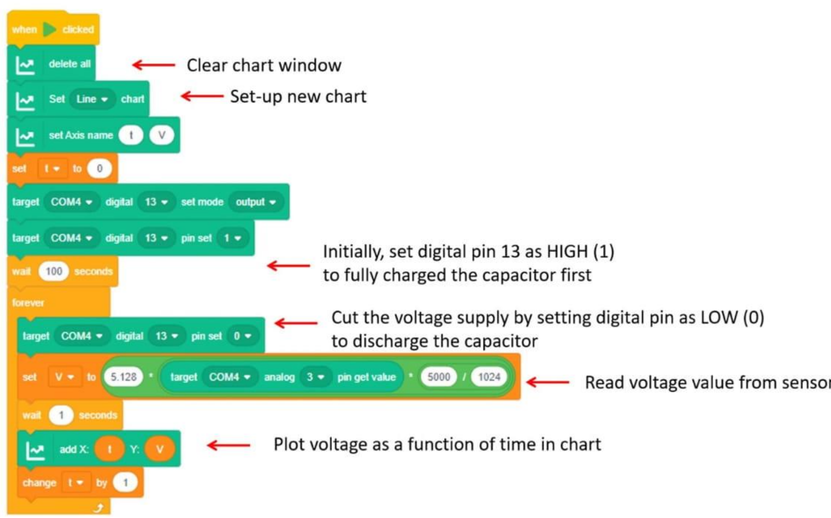


Figure 7. Code for investigating time-varying capacitor voltage during charging process.



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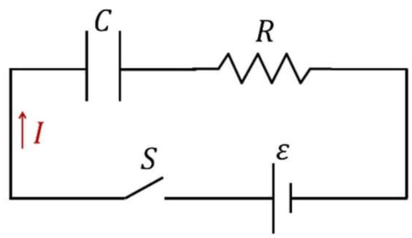

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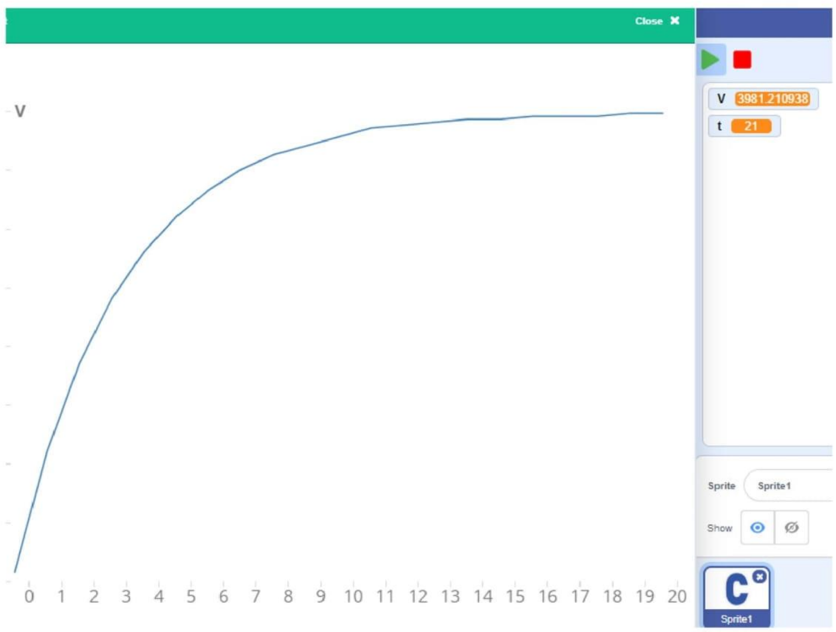
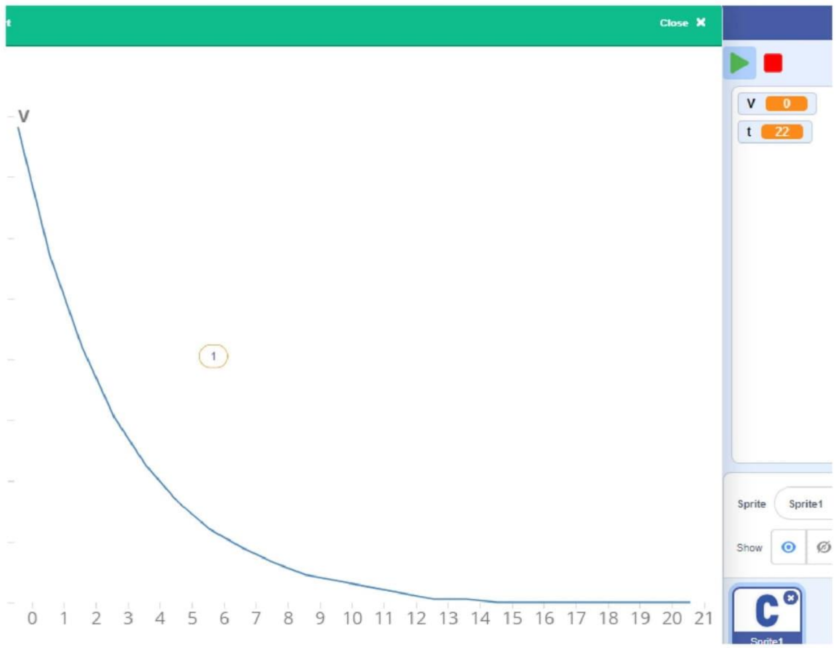


Figure 10. The time-varying voltage across capacitor during charging process presented in chart window available in common-coding builder. Voltage and time are in volt and second, respectively.

fast; then, the increment becomes slower until it reaches a steady maximum voltage. This result is in agreement with the theory presented in equation (5). Figure 11 shows the voltage–time graph when the capacitor is discharged. As predicted theoretically in equation (7), the experiment showed that the capacitor voltage decreases exponentially during the discharging process.

Data visualisation in the common-coding builder helps students understand physical phenomena with graph representation and connect experimental results with theoretical models. Moreover, with minimal knowledge of computer



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programming, students can do the activities at home. Although common-coding builder has advantages such as introducing a foundation of computational thinking to students with minimal knowledge of programming, it has several limitations. First, to connect the common-coding builder to Arduino UNO, we need to pre-install Java and the firmware application (ccb_connect.exe). Hence, the teacher has to give a prior explanation or tutorial to students. Second, common-coding builder for computers only works online. For students who work in inadequate internet facilities, it may become an issue.

4. Conclusion

Arduino and block-structured language programing, like common-coding builders, can be used to design various experiments to support physics learning. The apparatus is affordable, and the programming can be done easily by students who do not have prior knowledge of coding a program. Teachers can design experiments with various topics and assign students to try them at home. Since access to a laboratory is difficult for physics distance learning, this experiment can become an alternative to training students' practical skills, science process skills, and computational thinking skills. During a difficult time, such as the COVID-19 pandemic, it may be useful to support high school students or early year college students exploring physics from home.

Data availability statement

All data that support the findings of this study are included within the article (and any supplementary files). Q9 Q10

ORCID iDs

Elisabeth Pratidhina https://orcid.org/0000-0002-4634-375X
Wipsar Sunu Brams Dwandaru https://orcid.org/0000-0002-9692-4640

Received 15 March 2021, in final form xx xx xxxx
Accepted for publication 8 July 2021
https://doi.org/10.1088/1361-6552/ac12a6

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10. Bukti published online 28 Juli 2021

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Elisabeth Founda <elisa.founda@gmail.com>

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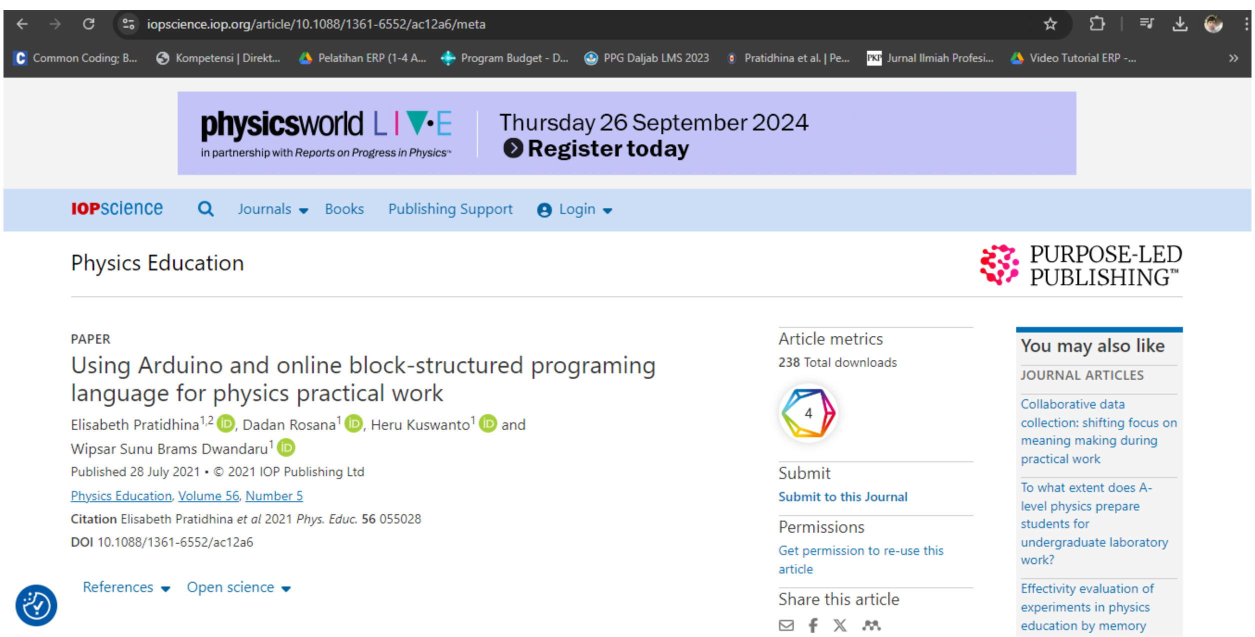


PAPER
Phys. Educ. **56** (2021) 055028 (11pp) iopscience.org/ped

Using Arduino and online block-structured programing language for physics practical work

Elisabeth Pratidhina[1,2], Dadan Rosana[1], Heru Kuswanto[1] and Wipsar Sunu Brams Dwandaru[1]

[1] Physics Education, Postgraduate Program, Universitas Negeri Yogyakarta, Jl. Colombo No. 1, Karang Malang, Caturtunggal, Depok, Sleman, Daerah Istimewa Yogykarta 55281, Indonesia
[2] Department of Physics Education, Widya Mandala Catholic University Surabaya, Jl. Kalijudan 37, Surabaya 60114, Indonesia

E-mail: elisa.founda@ukwms.ac.id and Herukus61@uny.ac.id

Abstract
Distance learning in physics is still facing challenges, mainly due to the difficult access to a laboratory for practical work. Practical work is an essential part of the physics classroom because it allows students to interact with authentic physics phenomena and develop their scientific abilities. In this paper, we propose alternative experiments that can be carried out at home with affordable apparatus. We explain the use of an Arduino UNO board and block-structured programming environment to design physics experiments about investigating light-emitting diodes and capacitor characteristics. Block-structured programming in the common-coding builder is used because it has extensive features such as plotting data in a graph directly and programming the Arduino board. Moreover, a user with no prior knowledge of programming can use it easily.

Keywords: Arduino, physics, practical work, block-structured programming, distance learning

Supplementary material for this article is available online

1. Introduction

In the past, the distance learning modes main obstacle was the lack of interaction among students and teachers. The advanced communication technology that we have nowadays has a significant impact on the distance learning process. The interaction among students and teachers during distance learning has been tremendously enhanced by various communication platforms and learning management systems. However, teaching physics in a distance learning mode is still challenging.

Practical work plays an essential role in physics education to develop students' scientific ability, understand the process of scientific investigation, and connect the real physical world with theory [1–3]. The challenge for physics education in distance learning mode is how students can experience laboratory work effectively and safely. There are some alternatives for this challenge, including using computer simulations and portable experiment kits [4, 5]. Computer simulation may engage students in scientific processes such as manipulating variables, observing phenomena, and analysing the relationship among variables. However, it cannot bring authentic laboratory experience. Students can physically work on objects, practice using instruments safely, be aware of real measurement uncertainty, observe the real phenomena, and create conceptual models of the physical world.

Students may perform laboratory work at home by using an experiment kit. There are various experiment kits on the market, but they are mostly pricy and only can be used for specific experiment topics. However, the recent development of low-cost microcontrollers and sensors offers feasibility in bringing affordable physics experiment tools to distance learning [6].

Arduino is a low-cost microcontroller that has been widely used for physics education [7–10]. It can be connected with various sensors to measure many physical quantities [8, 11, 12]. Usually, Arduino programing uses C or C++ programming language. However, it might be difficult for a teacher to implement the programing language in the physics classroom because students may not have prior knowledge of computer programming [13]. Fortunately, a user-friendly programming environment, called block-structured programming language, can be used to program Arduino. In a block-structured programming language, the developer only needs to drag and drop the blocks to construct a program, and they do not have to memorise the syntax to write the code.

This paper shows the use of Arduino and block-structured programming language provided in common-coding builder [14] for a didactic physics experiment investigating capacitor and light-emitting diode (LED) characteristics. Common-coding builder is based on Scratch, a widely used block-structured programming language in STEM education [15]. However, the common-coding builder offers extension features such as chart, Google Sheet, and Arduino programming. Those features are useful for setting up physics experiments with Arduino, getting and analysing the data.

2. Investigating the characteristic of LED

2.1. Hardware set-up

In this experiment, the apparatus consists of an Arduino UNO board, a USB serial cable, LEDs, a 220 Ω resistor, a 10kΩ potentiometer, a breadboard, a computer with Windows operating system (OS), and internet connection. The circuit diagram to investigate the characteristic of LED is shown in figure 1. In this set-up, Arduino UNO is used as a voltage source, a current, and a voltage sensor. A potentiometer is used as a voltage divider. By adjusting the potentiometer, we can change the voltage across LED, and then measure the current.

2.2. Programing

To program Arduino UNO for a voltage source, a current, and a voltage sensor, we have to program it through the common-codding builder. Common-coding builder can be accessed online using a browser at https://common-coding.com/. The initial layout is presented in figure 2. To allow Arduino programming, we need to choose Arduino Windows extension (see figure 3); after that, download and run firmware to connect the Arduino Uno hardware to the software. The firmware application, ccb_connect.exe, is running in a Java environment. The complete procedure to allow connection between Arduino UNO and the common-coding builder for the first time is explained in the supporting information (available online at stacks.iop.org/PED/56/055028/mmedia). As a disclaimer, we test the common-coding builder in the Windows OS environment only due to the limitation of devices. However, the common-coding builder also provides features for Mac OS.

The code to program Arduino UNO in investigating the characteristic of LED is shown in figure 4. In this set-up, voltage and current are

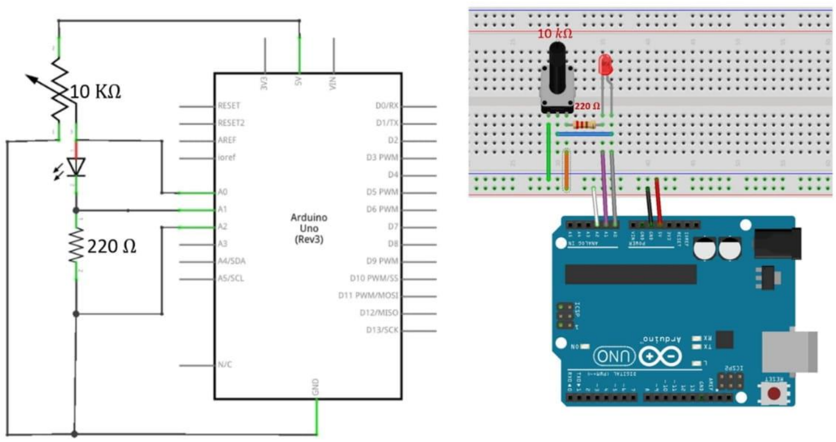


Figure 1. The circuit used in the experiment to investigate the characteristic of LED.

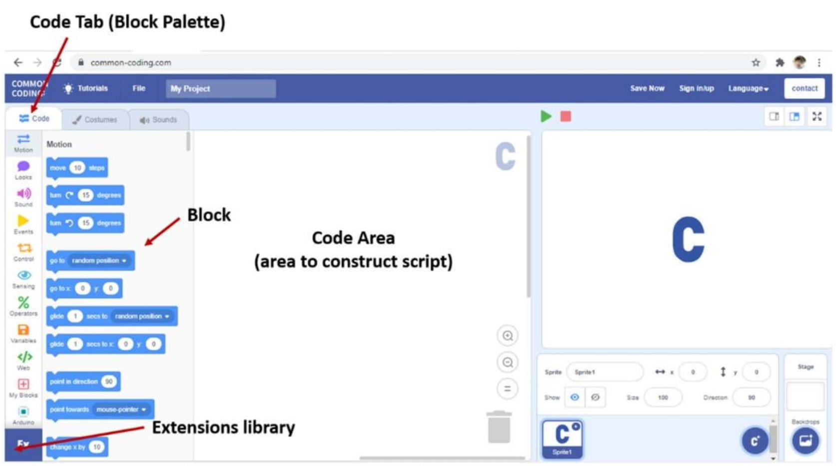


Figure 2. The layout of common-coding builder.

measured from the value recorded by the analog pin of Arduino UNO.

2.3. Discussion

Typically, LEDs consist of semiconductor materials which have an energy bandgap. Enough applied voltage can cause electrons to jump from one material to another. The electron transition from the conduction to the valence band causes light to emit. The voltage at which the first transition occurs is called the threshold voltage. The first transition can be observed from the first light emitted or the first current measured in the circuit.

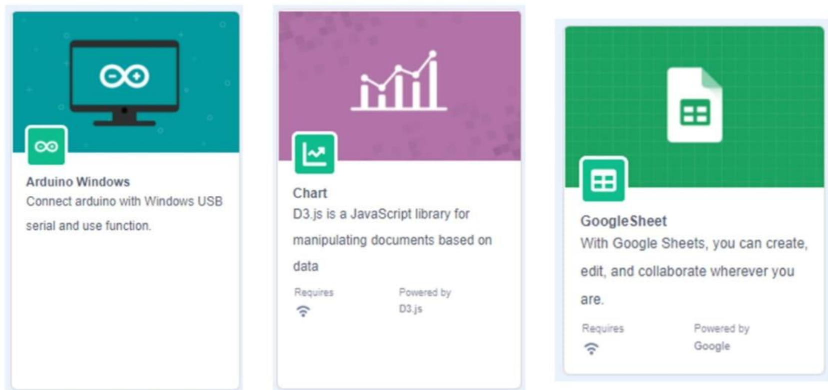


Figure 3. Some extensions library in common-coding builder, i.e. Arduino Windows, chart, and Google Sheet.

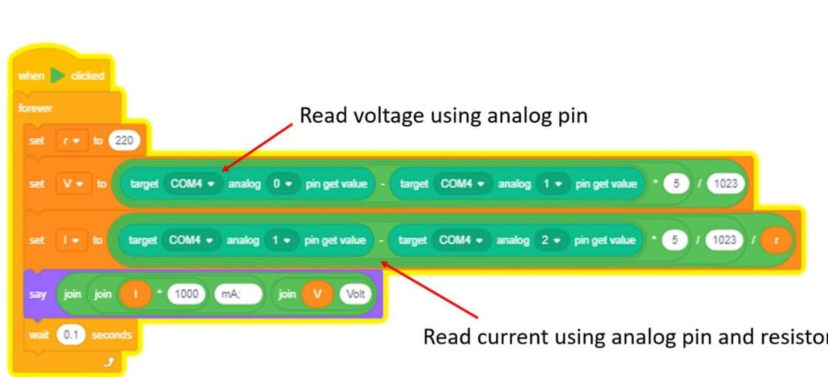
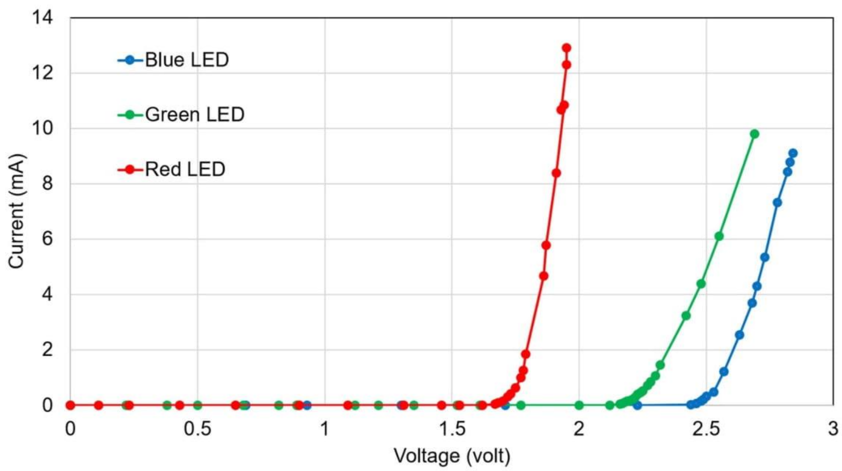


Figure 4. The code for investigating LED characteristic using the common-coding builder environment.

The energy band gap of each LED can then be calculated with equation (1). Each type of LED is fabricated from various semiconductor materials; thus, they have various energy bandgaps. Different semiconductor materials will produce multiple colours

$$E_{\text{gap}} = eV_{\text{threshold}}. \quad (1)$$

In this experiment, we investigate the voltage–current relationship in red, green, and blue LEDs. As shown in figure 5, for low applied voltage, current cannot flow through the LED. After the applied voltage is surpassing a specific threshold voltage, the current starts to flow. Table 1 presents the measured threshold voltage. Current in the red LED starts to flow when the applied voltage is around 1.67 V. For the green LED, the applied voltage should be higher than 2.16 V to allow current flow. Meanwhile, the blue LED requires the highest applied voltage, i.e. 2.46 V, to allow current flow.



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LED	$V_{\text{threshold}}$ (eV)	E_{gap} (eV)
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The experiment may help students to understand how a circuit with an LED works. It also can introduce the quantum properties of solids to students. Furthermore, this experiment can be extended with more colours of LED for determining the Planck constant value [16].

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$$\varepsilon - \frac{q}{C} - IR = 0 \tag{2}$$

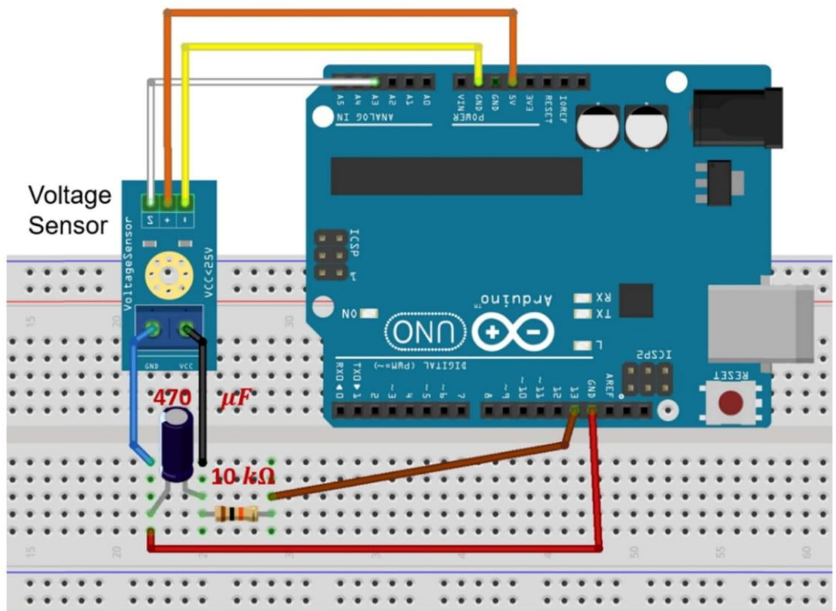

Figure 6. 'Investigating capacitor' experiment set-up.

where ε is the voltage source, IR is the voltage across the resistor, and $\frac{q}{C}$ is the voltage across the capacitor. By substituting $I=\frac{\mathrm{d}q}{\mathrm{d}t}$ and dividing all terms by R, equation (1) can be written as:

$$\begin{aligned}\frac{\varepsilon}{R}-\frac{q}{RC}-\frac{\mathrm{d}q}{\mathrm{d}t}&=0\\ \frac{\mathrm{d}q}{\mathrm{d}t}&=-\frac{q-C\varepsilon}{RC}\end{aligned}. \tag{3}$$

By solving equation (3) and using an assumption that the capacitor is initially discharged, we can yield charge in the capacitor as a function of time, i.e.:

$$q(t)=C\varepsilon\left(1-\mathrm{e}^{-\frac{t}{RC}}\right). \tag{4}$$

Since $V=q/C$, the voltage across the capacitor, $V_{\mathrm{c}}(t)$ can be expressed as:

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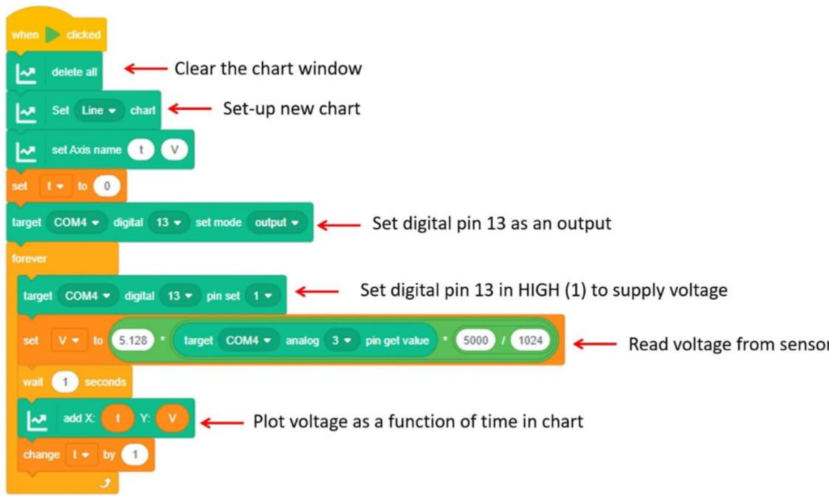

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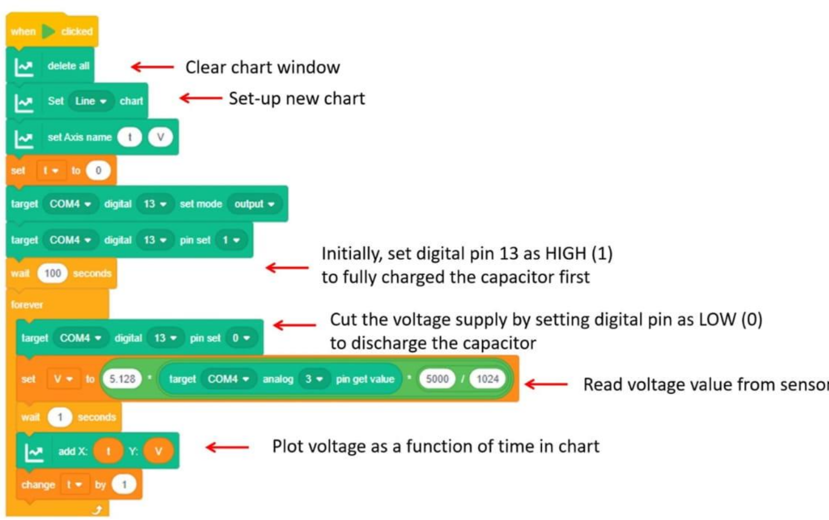

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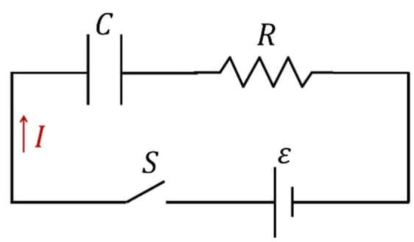
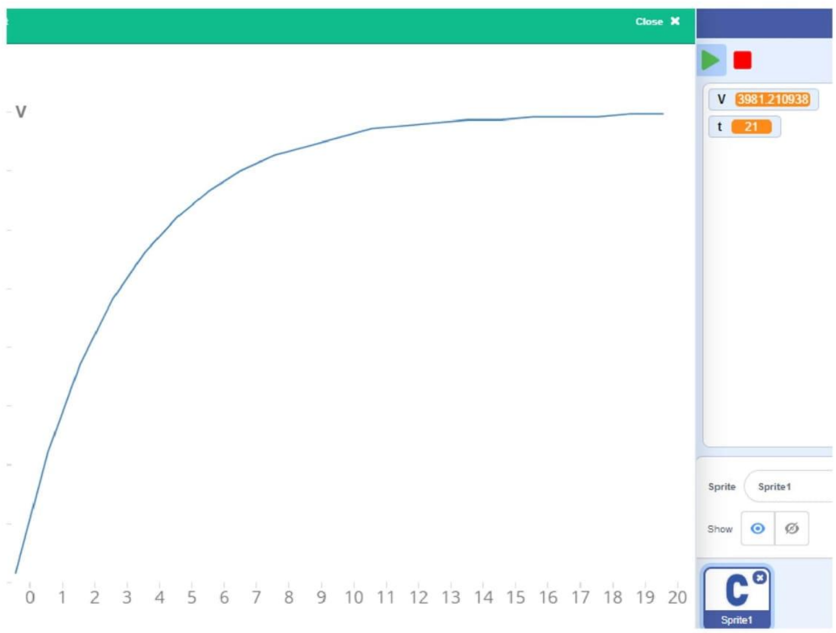


Figure 9. Basic circuit for 'investigating capacitor' experiment.



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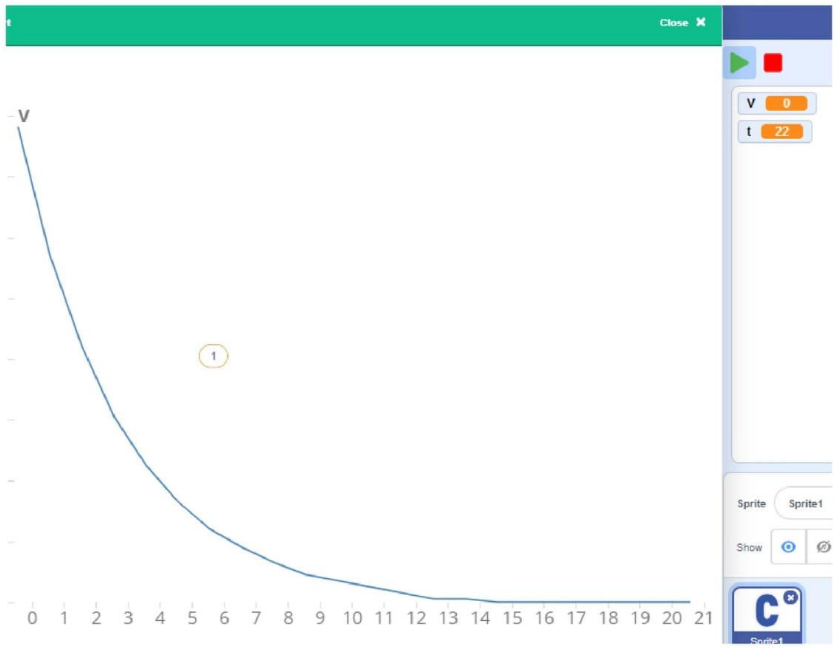

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Acknowledgements

The authors would like to thank the Indonesian Ministry of Education and Culture, which has funded this research through a doctoral dissertation grant.

ORCID iDs

Elisabeth Pratidhina https://orcid.org/0000-0002-4634-375X
Dadan Rosana https://orcid.org/0000-0003-4987-7420
Heru Kuswanto https://orcid.org/0000-0002-2693-8078
Wipsar Sunu Brams Dwandaru https://orcid.org/0000-0002-9692-4640

Received 15 March 2021, in final form 14 May 2021
Accepted for publication 8 July 2021
https://doi.org/10.1088/1361-6552/ac12a6

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Elisabeth Pratidhina received her MS degree in physics from Korea Advanced Institute of Science and Technology, Republic of Korea. She is currently a doctoral student at Universitas Negeri Yogyakarta and a lecturer at the Department of Physics Education, Widya Mandala Catholic University Surabaya, Indonesia.

Wipsar Sunu Brams Dwandaru holds a PhD in physics from Bristol University, United Kingdom. Currently, he is a lecturer at the Department of Physics Education, Universitas Negeri Yogyakarta, Indonesia. His main research interest is condensed matter physics and nanomaterial.

Heru Kuswanto holds a doctoral degree in physics from Jean Monnet University, France. Currently, he is a professor at the Department of Physics Education, Universitas Negeri Yogyakarta, Indonesia. His research interests are optoelectronics and physics mobile learning.

Dadan Rosana holds a doctoral degree in education from Universitas Negeri Yogyakarta. Currently, he is a professor at the Department of Science Education, Universitas Negeri Yogyakarta, Indonesia.